An improvement of the water situation at Rukole Primary School in Tanzania

How to purify water that does not exist

Bachelor thesis within drinking water engineering

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Gothenburg, Sweden 2018
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Bachelor thesis ACEX10-18-80

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Cover: [Some of the students at Rukole Primary School]

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Preword

This bachelor thesis comprises 15hp and is the termination of the first three years at the civil engineering program at Chalmers University of Technology. The project is a collaboration between the project group, Engineers Without Borders Sweden, Mavuno Project in Tanzania and Norconsult AB in an effort to improve the water situation in Karagwe. It is an evidence for the project grout that civil engineering can make a difference in rural areas by helping people help themselves. If nothing else is mentioned all rights to figures and tables in this report belong to the authors.

The field study wouldn't have been possible without scholarships from SIDA, ÅFORSK and the fund of Torsten Jansson. In addition, the construction of a new rainwater tank wouldn't have taken place if it weren't for the sponsors JVAB, NightTech and all those who contributed through swish and baking sales. Above financial support, there are several persons which have been important in this project and deserves recognition for their work.

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Gothenburg, May 2018
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Abstract

Clean and safe drinking water is a necessary resource and a human right. Safety and accessibility of it is today a major problem worldwide since 1.5 billion people have low or limited access to drinking water. The lack of technical solutions and sufficient capital causes millions of people to die each year as a result water scarcity.

In this study, the water situation at the primary school in Rukole village, in Karagwe district, northern Tanzania has been studied. The installed tanks of that time, with purpose to collect water from local rooftops where old and defective. The quality of the water was poor and the quantity minimum. This is one of the reasons why over 400 students are ill every day and three students have passed away in two months. Therefore, it is important to investigate how the water situation at Rukole Primary School can be improved, both in view of the microbial quality of the water and its quality to improve their health. The purpose was to identify the worst dangers of the water system and to assign and propose the measures that improve the drinking water situation the most. In addition, the work also includes implementation of the most suitable and sustainable solutions for the school.

To identify the most urgent risks at the school, a risk assessment was made. For the quality, the worst risk identified was contamination of feces reaching the drinking water, and for the quantity, the worst risk was identified as the number of students is too high compared to the size of the water tanks. Further, a multi-criteria decision analysis was done with respect to availability, trust in the solution, cost and risk reduction, this to find the most appropriate and sustainable solutions to reduce the risks. The result of the analysis showed that the construction of a new rainwater tank and boiling were the most suitable technical solutions for the school. In addition, the analysis showed that trust in technical solutions increased in combination with education, therefore, education is an important part of the results.

The study included the construction of new rainwater tank, its financing, planning and project management before construction start. The goal of the collection was achieved thanks to donations from companies and individuals, resulting in a 90 m^3 rainwater tank that could provide the school's 1500 students with drinking water. To achieve a sustainable implemented solution, the school and the students were involved in the collection of local material, to make them be aware of their property and thus take responsibility for maintenance.

The study also showed that the knowledge about water management and hygiene was insufficient among the students, and this is an issue essential for improving water quality. Therefore, education about water management and hygiene was implemented, focusing on the technical solutions, something that the multi-criteria decision analysis confirmed. The education was always carried out by the teachers at the school, to achieve a sustainable solution by continuing the education even after the project team left.

En förbättring av vattensituationen på grundskolan i Rukole, Tanzania

Att rena vatten som inte finns

Kandidatuppsats inom Samhällsbyggnadsteknik

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Sammanfattning

Rent och säkert dricksvattens är en nödvändig resurs och en mänsklig rättighet. Säkerheten och tillgängligheten är idag ett stort problem världen över, då 1,5 miljarder människor har låg eller begränsad tillgång till dricksvatten. Bristen på tekniska lösningar och kapital gör att miljoner människor dör varje år som en följd av brist på rent dricksvatten. I denna studie har vattensituationen på grundskolan i Rukole, i norra Tanzania, studerats. Skolan använde två gamla defekta tankar för att samla upp regnvatten från närliggande tak, kvalitén på vattnet var låg och den lilla mängd vatten som fanns var långt ifrån tillräcklig. Detta är en av orsakerna till att över 400 elever är sjuka varje dag och att tre elever har avlidit under två månaders tid. Av dessa anledningar är det av yttersta vikt att undersöka hur skolans vattensituation kan förbättras.

I denna rapport undersöktes möjligheterna att förbättra dricksvattensituationen, både med avseende på vattnets mikrobiella kvalitet och dess kvantitet, på grundskolan för att främja elevernas hälsa. Syftet var att identifiera de värsta farorna för vattensystemet samt att utse och föreslå de åtgärder som förbättrar dricksvattensituationen mest.

För att fastställa de värsta farorna gjordes en riskbedömning på vattensystemet. Den värsta identifierade risken med avseende på kvalitet bestämdes till att fekalier når dricksvattnet, och den värsta med avseende på kvantitet bestämdes till att vattentankarnas storlek är otillräckliga jämfört med antalet elever. För att bestämma vilken åtgärd som krävdes för att eliminera dessa, gjordes en riskhanteringsanalys med avseende på tillgänglighet, tillit till lösning, kostnad samt riskreduktion, Resultatet av analysen visade att byggnation av ny regnvattentank och kokning var de mest lämpade tekniska lösningarna för skolan. Dessutom visade analysen att tilliten till de tekniska lösningarna ökade i kombination med utbildning, därför är utbildning en viktig del av resultatet.

Studien innefattade byggnation av en ny regnvattentank samt dess finansiering, planering och projektledning innan byggstart. Insamlingens mål uppnåddes genom donationer från företag och privatpersoner och resulterade i att en 90 m^3 regnvattentank kunde byggas i syfte att förse skolans 1500 elever med dricksvatten. För att uppnå en hållbar implementerad lösning involverades skolan och eleverna i insamlingen av lokalt material, i syfte att de skulle känna ansvar över sin egendom och därmed ta ansvar för underhåll.

I studien visades även att kunskapen om vattenhantering och hygien var bristfällig bland eleverna och detta är av stor vikt för att kunna förbättra vattenkvalitén. Därför implementerades utbildning om vattenhantering och hygien, med fokus på de tekniska lösningarna multikriteriebeslutsanalysen visade. Utbildningen genomfördes alltid av lärarna, i syfte att uppnå en hållbar lösning genom att utbildningen fortgår även efter projektteamet lämnat.

Acronyms and abbreviations used in text

ALARP	As Low As Reasonable Practicable
E.coli	Escherichia Coli, family of bacteria living in the intestinal of warm blooded animals
EHEC	Enterohemorrhagic Escherichia coli
EWB	Engineers Without Borders
IFRC	International Federation of Red Cross and Red Crescent Societies
ISO	International Standardisation Organization
LRV	$\log_{10}$ reduction value
MCDA	Multi-Criteria Decision Analysis
MPN	Most Probable Number
NE	Swedish National Encyclopaedia
SODIS	Solar Water Disinfection
Tank 1	Rain water tank, above ground at Rukole Primary School
Tank 2	Underground tank at Rukole Primary School
TBS	Tanzanian Bureau of Standards
UNA	United Nations Association
WHO	World Health Organisation

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1.Introduction

Water is the single most important provision to humans and according to United Nations Association of Sweden (2017) it is also vital in industries and agriculture. At the same time, clean water supply and sanitation is one of the greatest challenges worldwide (Svenskt Vatten, 2013). There are major differences in water use throughout the world, 83% of those who are suffering from water scarcity are living in rural areas and 40% out of these are living in sub-Saharan areas of Africa (UNA Sweden, 2017). For instance, less than 7% of the rural population in Tanzania are using safely managed drinking water services (World Bank, 2015). Karagwe district, a rural area in the northwest part of Tanzania, is one of the districts suffering greatly from water scarcity. In addition to this, the current water sources in the district are of poor quality and the sanitation possibilities are inadequate.

1.1 Background

Approximately 1,5 billion people in the world have access to basic or limited sanitation and water services. Basic services are defined as having access to an improved water source with a round trip of 30 minutes. Limited services indicate that it takes more than 30 minutes to collect water. In addition to that, 580 million people collect water from unprotected wells and springs as well as untreated surface water from lakes, ponds, rivers and streams (World Health Organization, 2017).

According to the WHO (2018), the safety and accessibility of drinking water is a great problem throughout the world and improving access to it can result in enormous health improvements for those who lack drinking water. “To ensure everybody’s access to clean water and sanitation” is number six of the 17 development goals to transform the world by United Nations (n.d.). Theoretically there is enough fresh water to achieve this but because, for example the lack of improved technical solutions and capital, millions of people die every year. Since diseases caused by inadequate water supply often affect children the most, a majority of the deceased are children. (United Nations, n.d.).

1.1.1 Context

The United Republic of Tanzania is approximately twice the size of Sweden with a land area of around 950 000 km^2 and a population of 52 million people. According to World Bank (2016), approximately 68% of the population live in the rural areas of Tanzania. The official language is Swahili but beside that, English and around 120 native languages are being spoken (Sveriges Ambassad, 2017a.). The capital of Tanzania used to be Dar es Salaam, but the government recently changed it to Dodoma. The country is divided into several regions, which are subdivided into multiple smaller districts.

Tanzania is predominated by large differences in altitude, which causes a diversity in both climate and vegetation between the different parts of the country. Every year there are two raining periods. During March to May, the long rain season occur, while the short rain season come about during November until December. During these rain seasons, there are greater risks for floods which can lead to closed bridges, affected traffic situations, power outage and earth slip (Sveriges Ambassad, 2017b). Because of global warming the rain seasons are more irregular now than usual.

The most important income for Tanzania is agriculture and the economic growth is relatively high averaging 6-7% a year (Sveriges Ambassad, 2017a). Even though the poverty rate has declined, the absolute number has not decreased. About 47% of the population are currently living below the global poverty line which is 1.90 US dollar a day (World bank, 2011). In addition to that, 12 million or 23% of Tanzanians earn even less, 0.60 USD a day, which classifies as living in extreme poverty. In 2009, the UN International Fund for Agriculture Development gave a supplementary loan for 56 million USD to Tanzania in an effort to improve the financial situation and the low income for the rural farmers (Africa Research Bulletin, 2009). This is one example of how Tanzania benefits from financial aid, but aid doesn’t have to be governmental like this previous case. It can also be separate organisations financing projects or none governmental-organisations in their own interest.

Mavuno is one of the non-governmental organisations in Tanzania that receive financial aid and several of their projects are depending on that. The organisation was founded in 1993 by local farmers and their goal is to "Strengthen the ability of the community to identify, manage and control available resources for their sustainable development". The main intention is to improve the quality of life for the people in Karagwe district (Mavuno, n.d.). Engineers Without Borders is a non-political and religious organization who works with projects in development areas with the same aim as Mavuno. For instance, in 2012, Engineers Without Boarders started a cooperation with Mavuno to improve the constructions of rain water tanks in Karagwe (Swedish Engineers, 2013).

Rukole is a poor village in Karagwe district, in the northwestern parts of Tanzania, see Figure 1. The area is characterized by its topography and vegetation since it is approximately 1600m above sea level. The village is also one of the beneficiaries from Mavuno and has approximately 2000 inhabitants. Because of the topography, it is far to the nearest fresh water source for the farmers and villagers therefore, many households and schools have rain water harvesting tanks to collect drinking and household water. However, this water is not enough for the inhabitants and it is of poor quality. Rukole Primary School, with approximately 1500 students and 18 teachers is one of about 100 schools in Karagwe district in need of improved water sources. The students drink water directly collected from rain water tanks without any treatment.

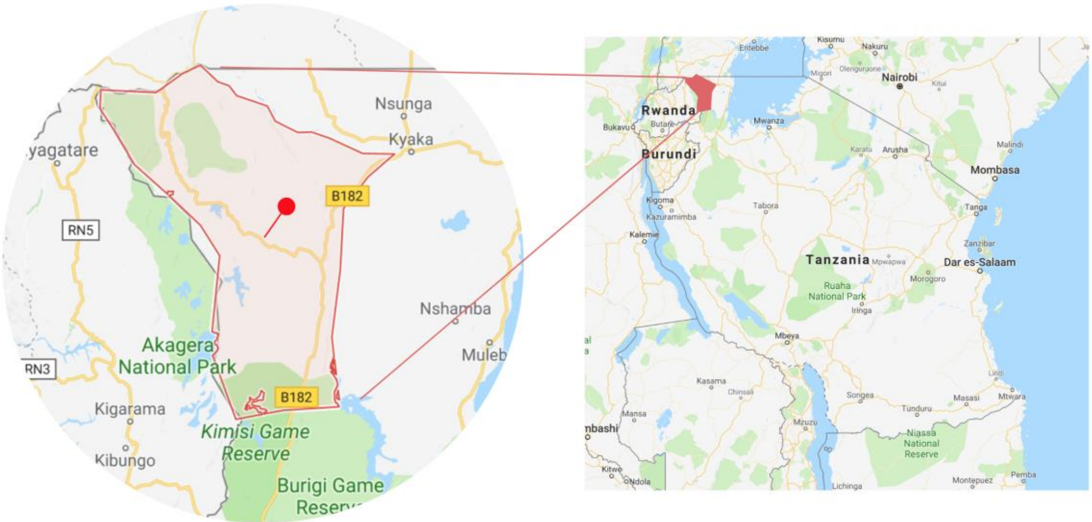


Figure 1 Map over Tanzania and Karagwe region with Rukole village as a red pin. Map material collected from Google Maps

1.2 Aim

The aim of this project is to investigate the possibility to improve the drinking water situation with regard to both quantity and micro-bacterial quality at Rukole Primary School by means of education and technical solutions. The best technical solutions for the school will be presented in this written report. The most appropriate and sustainable solution will be implemented at the school. The handover of the implemented solutions will be performed with the aim that the owners will take responsibility for the solutions.

1.3 Limitations of the study

Earlier projects done by Engineers Without Borders and Mavuno used material for analyzing three types of bacteria, Escherichia Coli, Coliform bacteria along with Enterococci. Since there were already instruments on site purchased for these different bacteria this field study is focusing on the same three. However, there are other bacteria that affect the quality of drinking water that have not been analyzed.

1.4 Research questions

Research questions that are the foundation for the investigation of the on the drinking water situation at Rukole Primary School, both with regard to the microbial quality and quantity:

- *Which hazards result in the most emergent risk?*
- *Which solutions are the most appropriate and sustainable as well as improves the drinking water situation the most?*
- *Which of the suggested solutions is the most urgent and is in need of implementation during this project?*
- *How will the transmission of the implemented solutions be formed for the school to feel ownership and will take responsibility of the solution?*

2. Theoretical background

Prior to the field study a literature study was made in order to be well prepared and informed in the subject of drinking water. This information was combined with knowledge from other projects in developing regions where the aim is water purification as well as quantification. The purpose of the study is also to learn about which bacteria are dangerous to individuals and how they affect the body as well as local and international guidelines for drinking water to avoid negative health aspects.

2.1 Microbial waterborne diseases in drinking water

There are several different microorganisms existing in the human body in a natural way but not all these organisms are harmful, some are necessary (Modin, 2017). Those organisms which causes diseases in some way are called pathogens. Many pathogens are spread through water and people can get exposed to these by drinking contaminated water or swim in it (Moseley, 2014). As well as that, the bacteria can be spread through food which has been irrigated by contaminated water (Folkhälsomyndigheten, 2016). When it comes to these so-called pathogens, which cause a number of different waterborne diseases, they affect the gastrointestinal tract the most. Even though the symptoms vary depending on the disease, the most common symptoms are diarrhea, stomach pain, vomiting, nausea and headache (Folkhälsomyndigheten, 2016). Even though diarrhea can be a symptom of other diseases it alone can also be classified as a disease. It is the most widely known disease connected to water and the disease alone takes approximately 842 000 lives every year which could be avoided if the sustainable development goals would be achieved (WHO, 2017). Above that, both the diseases typhoid and cholera are spread as a result of poor or inappropriately managed water and sanitation services, these waterborne diseases can be avoided if a good biological quality has been established (WHO, 2011).

There are great variations in how people react towards different pathogens, in general, if a person is exposed to a certain pathogen for a long time he or she becomes immune (WHO, 2011). However, young, elderly, pregnant women and people with low immune capacity are more vulnerable to pathogens and can therefore be more affected by them.

In order to make an assessment of the microbiological quality of the water different types of bacteria can be analysed. They are called indicator organisms and can indicate fecal impact of the water, however, these indicators are not entirely reliable and should therefore be complemented with risk assessments and continuous evaluation (Svenskt Vatten, 2018). Coliform bacteria and E. coli are both used as indicators. Above this, the bacteria Enterococci are used for the same reason, to indicate fecal impact of the water (Livsmedelsverket, 2017a).

2.1.1 Indicator organism as quality parameter in drinking water

To demonstrate inadequate purification, suspected contamination or other issues regarding drinking water, indicator organisms are used (Svenskt Vatten, 2017). These organisms can indicate, for instance, fecal impact. Both Escherichia coli and Coliforms are what you call indicators, E-coli indicates solemnly fecal contamination while coliforms are more general and can indicate both fecal as well as other contaminations. These parameters recounts something about the biological quality of the water (Modin, 2017). To analyze the indicator organisms, E-coli and coliforms there is one ISO-method that is suitable for all types of water, even if it contains high amount of suspended matter and high background counts heterotrophic bacteria. This standard method is called SS-EN ISO 9308-2:2014 (colilert). The method is based on growth of target organisms, or bacteria, in a liquid medium. After the growth a calculation of the Most Probable Number of organism by reference to specific MPN-tables is carried out (Svenska institutionsstyrelsen 2014).

2.1.2 Coliform bacteria and Escherichia coli as indicator organism for fecal impact

Coliform bacteria are a collection name for several different bacteria (Oxfam, 2001) which are specific for intestinal canals of the human body and in warm blooded animals. They are almost always present in feces and are therefore a good indication that the drinking water is contaminated and that the need for improved purification is necessary. Oxfam (2001) states that 99% or more of the coliform bacteria are E.coli, so a majority of the coliforms are usually E.coli.

E.Coli is a collection name for several strains of gram-negative rod-shaped organisms that normally are found in the lower parts of the intestinalis in all warm blooded species. Most of these are harmless but there are a few pathogens among them (Moseley, 2016) Enterohemorrhagic Escherichia coli is one of the pathogenic sub-groups of E.coli, it manifests itself through abdominal pain and bloody diarrhoea, above this approximately 10% of the cases lead to renal failure as a result of haemolytic-uremic syndrome which can be fatal. Small children and elderly are especially vulnerable for this disease. The characteristics of the Ehec-bacteria is how it binds closely of the cells inside the intestine and produces toxins, so called Shiga Toxins. These toxins survive in acidic environments which protects the bacteria while passing through the gastric secretion. Following strains are also classified as pathogens (Moseley, 2016):

- EIEC- Enteroinvasive Escherichia coli
- EPEC- Enteropathogenic Escherichia coli
- ETEC- Enterotoxigenic Escherichia coli

2.1.3 Enterococci

Enterococci, like the other two indicator organisms presented above exists naturally in the intestinal of humans and animals (Livsmedelsverket, 2017b). In addition, the bacteria can be found in plants, insects and soil. Enterococci are not as good fecal indicator as total coliforms or e-coli since they can grow far away from contamination sources (Modin, 2017). However, there is evidence that the bacteria can carry specific genes that codes for different diseases. For instance, the specie Enterococcus faecalis can cause urinary infection, bacterial sepsis and cardiac inflammation (Nationalencyklopedin, n.d). Even though Enterococci can indicate fecal impact on drinking water it is more common to find them within health care, which is one additional reason to why it is not as god as coliforms and E.coli. These bacteria are also more resistant to heat, cold, low pH values salt and dehydration compared to e-coli according to the Livsmedelsverket (2017b), above this they are also resistant to some antibiotics (NE, n.d).

2.2 Guidelines for drinking water

In order to protect public health, national governments and international organisations have created guidelines for drinking water regarding both quality and quantity. The Swedish and Tanzanian guidelines as well as more general guidelines are presented in the following section. These guidelines are recommended since following them, they will reduce hazardous risks to drinking water.

2.2.1. General guidelines

According to WHO (2011) there are no international standards for drinking water quality, however, the organisation establish scientific facts about water on which governments can base their on national standards. This is because the water situation varies throughout the world and that gives each country an opportunity to adapt standards that suits them as well as their current situation. Even though WHO doesn’t create any international standards or regulations, the organisation advocate governments to adapt the national standards according to minimum requirements. This is to ensure safe water for all.

Table 1 Water intake for ages 4 and older

Gender	Age [years]	Amount [L/day]
Boys	4-8	1,7
Girls	4-8	1,7
Boys	9-13	2,4
Girls	9-13	2,1
Boys	14-18	3,3
Girls	14-18	2,3
Men	19-70+	3,7
Women	19-70+	2,7

Svenskt Vatten (2017) says that water is clean and safe if it doesn't contain any microorganism, parasites or substances in amount or content which can be harmful to a person health. For the bacteria E.coli and Coliforms in all types of drinking water, both treated and untreated, there should be no bacteria at all detected in a sample of 100ml WHO (2011).

As for guidelines regarding quantity of water, a minimum of 15 litres per person and day should be available in emergencies, however, a higher value of 20 litres per person and day is desirable. (WHO, n.d). The amount of solemnly drinking water can vary widely depending on climate, workload and individual but it is normally between 2-16 litres per day. Table 1 shows how the water intake can vary depending on age and gender. The value includes both drinking water, water content of beverages and in food (Food and Nutrition Board, 2004).

According to Oxfam (2001) it is important to consider both quantity and quality when choosing water source. For instance, it is sometimes better to have a larger amount of water with lower quality than having little water of great quality. Moreover, having a larger storage of bad quality water can be better than a lot of small good quality sources when maintaining the system (Oxfam, 2001).

2.2.2 Swedish and Tanzanian guidelines for drinking water

Since drinking water shouldn't contain any microorganism, parasites or substances in amount or content which can be harmful to a person health there are some guidelines to facilitate the process of achieving this. If there is one single E.coli bacteria or Enterococci found in a sample of 100ml, the water going into distribution is unserviceable. However, if the water is packed, it is considered unserviceable if it is one bacteria in a sample of 250ml. When it comes to Coliform bacteria the tolerable number of bacteria is the same in both samples of 100 and 250ml, 10 bacteria or more and the water is considered unserviceable to people (LIVSFS 2017:2). This information is summarized in Table 2.

The Tanzanian Bureau of Standards (TZS 789:2003 5.4.2) has agreed on four different categories to define the microbiological quality of water with regard to E.coli and Coliform bacteria. To be classified as excellent the water must be completely free from any coliform bacteria and E.coli. If there are 1-3 Coliform bacteria in the sample of 100ml the water is classified as satisfactory, while it is suspicious if there are 4-10 bacteria. A completely unsatisfactory value for coliforms are more than ten bacteria in a sample of 100ml while it is also unsatisfactory if there are more than zero E.coli bacteria in an equal size sample (TZS 789:2003 5.4.2.). This information is summarized in Table 3.

Table 2 Swedish guidelines for tolerable amounts of coliform bacteria, E.coli and Enterococci in drinking water

Indicator	Drinking water in distribution	Bottled water
E.coli	Found (in 100ml)	Found (in 250ml)
Intestinal Enterococci	Found (in 100ml)	Found (in 250ml)
Coliform Bacteria	10 (number/250ml)	10 number/250ml)

Table 3 Tanzanian guidelines for amounts of coliform bacteria and E-coli in drinking water

Indicator	Excellent	Satisfactory	Suspicious	Unsatisfactory
Coliform Bacteria (sample of 100ml)	0	1-3	4-10	>10
E.coli (sample of 100ml)	0	-	-	>0

2.3 Risk assessment and risk management on water systems

To make sure that the guidelines are followed, a risk assessment and management can be done according to Figure 2. This is to identify the risks for one specific water system, as well as find appropriate solutions to eliminate the risk. There are several separate risks or hazards towards a water system which can affect it. According to WHO (2009) a hazard is physical, biological, chemical or radiological agents that can cause harm to public health, while a hazardous event is an event that introduces hazards to, or fails to remove them from the water supply. WHO (2009) gives an example to clear it out “Heavy rainfall (hazardous event) may promote the introduction of microbial pathogens (hazards) into source water”. In order to get a complete picture of the system and how these hazards affect each other one can carry out a risk assessment and create a so-called Risk Matrix (Techneau, 2008). It will help creating a cost-efficient solution to ensure a safe and stable water system. However, it is important to describe the water system as clear as possible first, which will support the process, from the catchment stage to the distribution to the consumer. This should be done on-site in order to have the most lifelike system (WHO, 2009).

It is also crucial that the weaknesses of the system are being identified, which hazardous events and hazards are most important in order to take actions towards it (WHO, 2009). When creating a risk assessment, it is necessary to be able to separate hazards from hazardous events and be sure what they mean.

Other information that should be collected before the assessment is relevant water quality standards in the current system as well as if there are any known changes in the quality due to weather and other conditions (WHO, 2009). In addition to this, what source of water is used, documentations of the storage, treatment of water and distribution should be included in the preparation work. In addition, the numbers of users of the water system is also necessary to be able to perform a good risk assessment (WHO, 2009).

The risk assessment is according to Techneau (2008) divided in to four parts and the fourth part is something that’s going on during the entire process, from risk analysis to risk reduction. This involves getting new information and update during the entire assessment. Moreover, one should analyse sensitivities, develop supporting programmes, document and assure quality along the way. Lastly, the creator should report and communicate, review, approve and audit the assessment in the end. This part is important because during the process things can change, hazards that were important in the beginning might not be as important in the end or vice versa. The risk assessment must be a living document from the start until the end (Techneau, 2008).

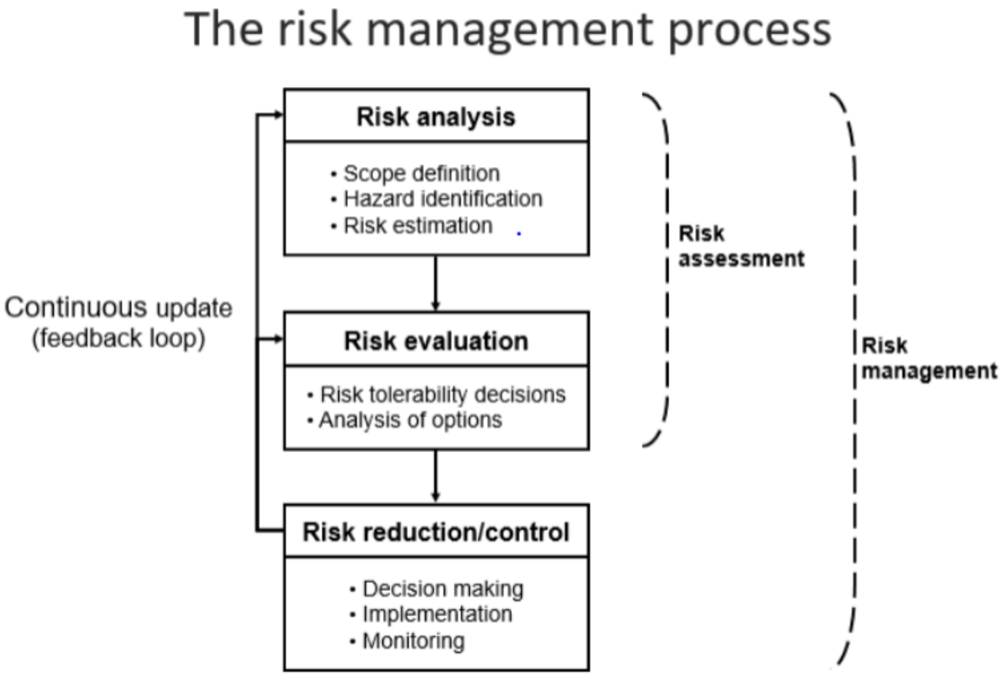


Figure 2 Risk assessment and managment illustrated by Techneau (2008). Published with permission.

2.3.1 Risk analysis

Techneau (2008) says that the first step is the risk analyse, where hazards are being identified and the risks are estimated. These hazards can be identified both on-site and by visual inspection, during desk-studies as well as historic events (WHO, 2009). To describe as many relevant hazards as possible it's desirable to combine all these methods. It is crucial to define the scope of the matrix as soon as possible in order to limit the risk assessment and only focus on the aim, which is to improve the water system (Techneau, 2008). These hazards can be towards both the quality as well as the quantity of the water. WHO (2009) explains that every risk is connected to one or several hazards and are described with two things. One thing is the possibility for a certain event to occur, for instance it can be a scale from every day to ever year, or one to five times. This is up to the creator of the risk assessment. The second thing is the consequence if the hazard would occur. Also, this grading is up to the creator but according to WHO (2009) usual values are, insignificant, major or catastrophic. However, the most important thing is the potential impact on public health even though there are other factors as well, for instance the climate. The reason for working in this way is because it is easy to decide which hazards are significant and which are not. To do this in a systemically way, it is recommended to draw a table, or a grid, which will be the risk matrix, with possibility on the y-axis and consequence on the x-axis.

Moreover, the description of the probability and consequence should be converted to significant figures on either a linear or exponential scale (WHO, 2009). It is a good thing to define the risk matrix-score which will indicate if the risk is significant or not before drawing it. The risk matrix is divided in to three regions where the first, and lowest one is green, which indicate that the risk that occurs in that region is acceptable, the second region means that the risks in that region is, "As Low As Reasonable Practice" (ALARP), and is illustrated with yellow in the risk matrix (Falk and Ohlin, 2015). Risks that are in the yellow region are acceptable if the risk reduction option that will reduce the risk is to expensive. The last and highest region is red and the risk that occurs in that region is unacceptable. The risk matrix is illustrated in Figure 3.

2.3.2 Risk evaluation

The second part is the risk evaluation, during this part all risk reductions options are analysed and graded (Techneau, 2008). There is a possibility to perform an Multi Criteria Decision Analyse, in order to include more aspects, for example, cost- estimation, customer trust, environmental effect etc. in the evaluation process. These options are graded among each other based on what the person carrying out the risk assessment believes is the most important. The reason for doing this is according to Techneau (2008) because even if a risk reduction option has great reduction potential it can be too expensive or have a negative effect to the environment. This might result in a risk reduction option or solution which is not suitable for the specific water system in the scope.

2.3.3 Risk reduction and control

The third part is the reduction/control where all final decisions regarding which hazards are the most important to eliminate or reduce. As well as that, it involves deciding which risk reduction option to use to fulfil the aim of improving the water system. The risk matrix value for each risk will hopefully become lower and change position in the matrix like follows in Figure 3 and Figure 4, when evaluating the reduction (Techneau, 2008). Another important aspect of this final part is the monitoring, after the risk reduction option has been implemented one need to monitor it to see if it is working as planned.

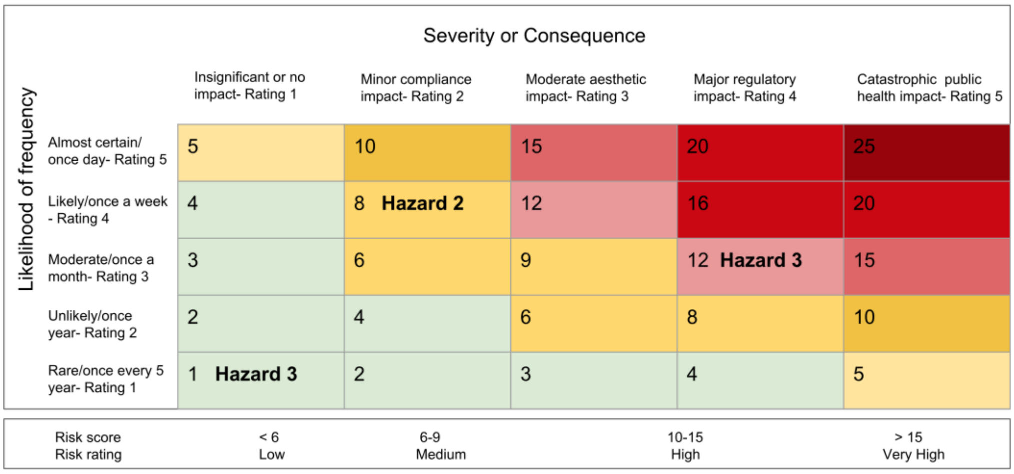


Figure 3 Risk matrix before risk reduction

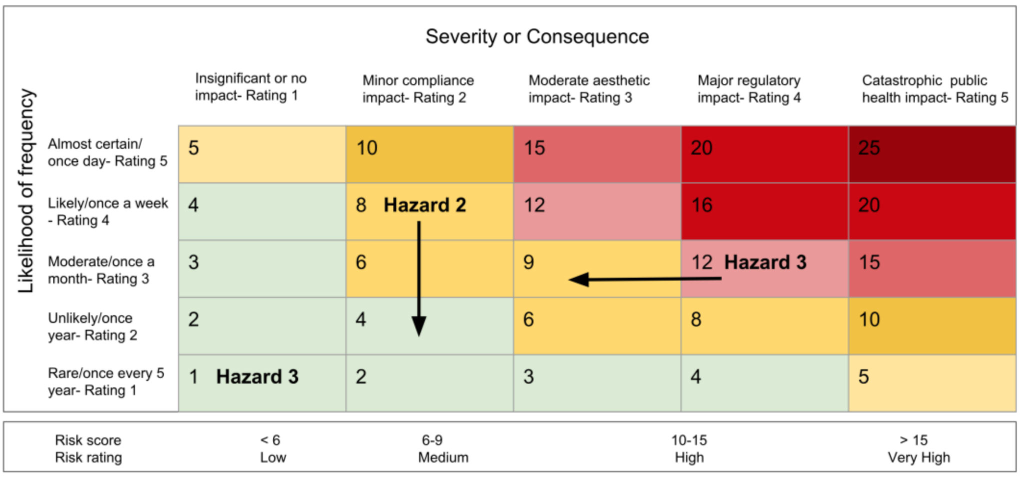


Figure 4 Risk matrix after risk reduction

2.4 Rainwater harvesting

Rainwater harvesting is a common method for collecting drinking and household water when there is water scarcity and lack of other fresh water sources. There are two type of rain water tanks to collect and store water, they are either built above or beneath ground level. Mavuno have built rain water tanks in Karagwe since 1990 (Swedish Engineers, 2013). In the beginning, they only built underground tanks because they are relatively cheap and easy to construct, see Figure 6. Later they started to build over ground tank, like Figure 5, but they are harder and more expensive to build. However, because of the pressure from the water it is easy to install a tap in the bottom of the tank. This improves the water quality and the design is safe for children. All the tanks are made of concrete and masonry, some have roof of steel and other have concrete roof, the sizes of the tanks vary between 20-100m^3 (Baraka, 2018-03-20; personal communication).

The catchment area is the area which is used for collecting the water and leading the water into the pipes, normally it is a roof or similar. The size of the needed catchment area can also be calculated with equation based on the Equation 1, where the collected water is calculated through multiply the catchment area with the rain depth in the specific area (Thomas & Martinson, 2007). In tropical areas about 85% of the rain is collected.

$$Collected\ Water\ [m^3] = Catchment\ area\ [m^2]\ x\ Rain\ depht\ \ [m]\ x\ 0{,}85$$

Equation 1. How to calculate collected water based on rain depth and catchment are

Figure 5 Overground tank

Figure 6 Under ground tank


(a)


(b)

Figure 7 First flush system connected to the storage tank (a), to the right the inside of the first flush cister (b)

Rain water is relatively free from contaminants except if it has adsorbed contaminations from animals or particles from the surrounding atmosphere or when it has run of hard surfaces, such as roofs etc. WHO (2011). Therefore, the quality of the rainwater can vary a lot during harvesting, storage and household use. Eventual hazards are avoided by keeping catchment areas clean, storage tanks covered, using a treatment method if necessary and proper hygiene at point of use. Moreover, the highest microbial concentrations are found in the first flush of rainwater, thereafter the concentrations decrease. Hence it is recommended that the first flush of the water should be removed before reaching the storage (WHO, 2011). Even though the first flush of water isn't suitable for drinking it can be used for other purposes. How much water that needs to be flushed away depends partly on the size of the catchment area.

Principles of first flush involves filling a separate container or first flush cistern, and when it is full the water with less impurities can flow to the tank. However, the cistern or tank need to be cleared and emptied before every rain season. In Karagwe district there are two different first flush systems, one is constructed in concrete at the same time as the tank. The second one is made of pipes and can be implemented on existing tanks. Figure 7 shows the first type, it consists of a cistern with two pipes which are cut and disconnected to each other. The cistern is connected to the tank with these pipes. When the rain starts, the cistern will start to be filled and once completely full, the pipes will rise and connect to each other because of the pressure from the water. When they are connected, the rest of the rain water with less impurities can flow though the pipes and into the storage tank instead of being collected in the first flush-cistern.

The second one was built according to Figure 8, water flows in to the container trough pipes and when the cistern is full a ball rises to the surface and block the pipe to the cistern. This results in water flowing straight to the storage tank instead. In the bottom of the cistern there is a tap from which the dirty water can be collected and emptied before the newt rain period. Since the system requires some maintenance, there is a risk that it won't be cared for which will mean that the first water won't be flushed away and the solution will not be long- term sustainable. However, one positive aspect is that this first flush is cheap variant available for household (Lovell, L, Bjersing, F, Burgren, M, Börjesson, T, 2017)

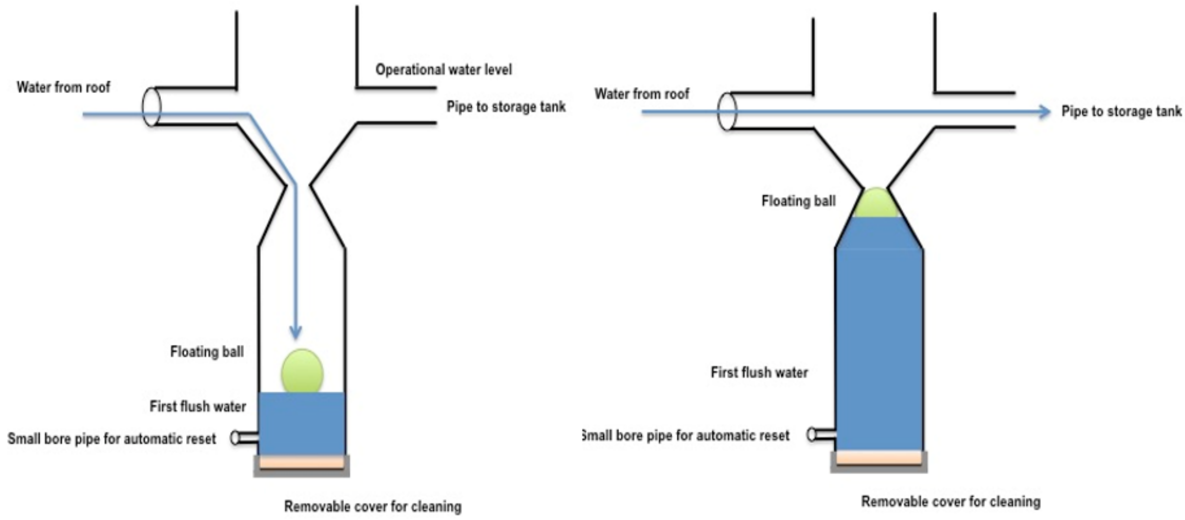


Figure 8 A first flush system with extern cistern and a floating ball designed by Lovell, Bjersing, Burggren and Börjesson (2017). Published with permission.

2.5 Microbiological barriers and treatment steps

To ensure that the quality of the water meet standard and regulations Svenskt Vatten (2017) explains that it is desirable to have many microbial barriers since the purpose of water treatment is to reduce the number of microorganism. Moreover, there are different recommendations for barriers depending on the quality of water, if it is surface water or ground water. The principles of microbiological barriers are either to inactivate or separate the microorganisms from the water. Livsmedelsverket advocate that all cleaning facilities for water should have at least one of each type. To decide how many barriers that are necessary, a Microbial Analysis can be done. In Sweden, there are five barriers which have been approved by the Livsmedelsverket (Svenskt Vatten, 2017).

1. Short, artificial infiltration of surface water (> 14 days)
2. Chemical flocculation and coagulation followed by filtration
3. Slow filtration
4. Primary disinfection, for example chlorination and UV-light
5. Membrane filtration (pores smaller than 0.1 micrometres)

2.5.1 Sand filter

There are different types of sand filtration categorized as slow or fast sand filtration. Only the slow filtration is an approved barrier according to Livsmedelsverket (Svenskt Vatten, 2017). Fast sand filter is an easy pre-treatment step that reduce the number of particles and help make the disinfection more effective (International Federation of Red Cross and Red Crescent Societies, 2008). The procedure is to pour water through a container of sand and gravel with an outlet on the bottom, where all the water that comes out have been processed through the different materials. Positives aspect is that the process is fast, effective to remove big particles, insects and germs that cause disease. In addition, a fast sand filter is a cheap alternative comparing to other treatment steps. Negative aspect is that it must be combined with other treatment steps that remove the micro-biological bacteria and improve the water quality better (IFRC, 2008).

Slow sand filter is a single treatment step to improve the water quality in a micro-biological, chemical and physical way. Furthermore, a slow sand filter can remove 99% or more of the E.coli population, if it is combined right (Oxfam, 2001), expressed in log_{10} reduction value, that is 2-6LRV (WHO, 2011). To get a slow sand filter to work properly it need to mature for a period of a few weeks before the slam cover and the micro-biological action is effective. Slow sand filter often is an open-topped box filled with some kind of clean sand and a layer of stones or gravel, which is showed in Figure 9. Raw water is put on the top and then sink by gravity, the purification takes place while the water passes the materials. A sand filter produces an active micro-biological layer, which help the purification and the filter can run for several weeks or more without cleaning. However, a slow sand filter needs regular maintenance and follow up and in addition, it takes a long time to treat the water (Oxfam, 2001).

In 2016 Gjerstad- Lindgren and Olivecrona performed a field study to help Mavuno choose a treatment method for drinking water, which could be implemented on their tanks. An investigation was made to see the possibilities of water purification on the rain water tanks at a school through a biosand filter. The biosand filter was a smaller version of a conventional slow sand filter and was adapted for household usage (Gjerstad-Lindgren & Olivecrona, 2016).

However, the result of the study was not representative for the whole water source because of the great variation in bacteria levels since the tank was often left open and dust was identified on the surface. Buckets used to collect drinking water with were also used for other purposes. Gjerstad-Lindgren and Olivecrona suggested that close hatches on the rainwater tanks, install pump systems and perform education about water, hygiene and sanitation could improve the performance of the biosand filter and the quality of drinking water.

Figure 9 shows how the water gets treated through the layers of sand, which always is covered with water. Contaminated water is poured out on the diffuser plate on the top and continue down through the bio layer, sand of different fractions and lastly through the gravel. Because of the water level in the container the pressure fills up the pipe and the treated water is pushed to the outlet.

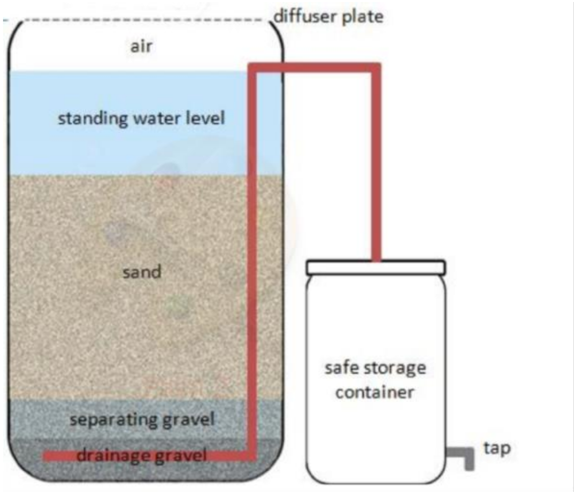


Figure 9 How a sand filter works. (Gjerstad & Olivecrona, 2016). Published with permission.

2.5.2 Ceramic filter and fabric filter

Both ceramic- and fabric filter works according to the same principle, there are pores which the water passes by with physical straining in the material and the particles get stuck in the pores (WHO, 2011). There can be both single and multiple porous surfaces. Pores that are too large, which might be the case with fabric filter, can be a problem because dangerous bacteria can be much smaller and will therefor pass by the fabric and contaminate the water. However, it is a good complement for further treatment steps to remove larger particles and suspended material (WHO, 2011). It is significant to clean the fabric between using it to remove the material (IRC, 2008). Cotton fabric is the most suitable and it should not be transparent in any way.

A ceramic filter works as a container with a hatch. Contaminated water is poured in at the top and collected in the ceramic pot. The water squeezes trough the ceramic pot and the filtered water reach a container with tap which works as an outlet. Different types of filter were analysed as household treatment devices in a survey in South Africa (Mwabi et al., 2011), ceramic filter was one of them. The silver-impregnated porous pot filter was displayed as the best both in reduction of chemical as well as microbial contaminant. The efficiency was as high as 99-100%. Depending on the size of the pores, a ceramic filter can be classified as a microbiological barrier, however the pores need to be smaller than 0.1 micrometre. For a porous ceramic filter the LRV can vary from 2-6 depending on the different properties of the filter while for fabric it is as low as from 1-2, both with regard to bacteria (WHO, 2011). Even though porous filter can be a good treatment step for drinking water one issue is the volume of water that can be treated. In addition, the flow rate decreases over time although the filter is cleaned (Soppe, Heijman, Gensburger, Shantz, van Halem, Kroesbergen, … Smeets,, 2015).

2.5.3 Chlorination

During ultimate conditions chlorine will inactivate all types of bacteria in drinking water, Oxfam (2001) suggests that this is because when chloride is added to water it creates certain compounds which will disturb the chemical processes bacteria need for survival. It is only the so called “Free Available” chloride who kills the bacteria (Oxfam, 2001). After adding the chemical to water it needs time to work, IFRC (2008), explains that it will take at least 30 minutes before the water is drinkable. Furthermore, if the water is very dirty, the water might need to be filtered and twice as much chlorine added to reach the same quality. These 30 minutes are called “contact time” and even though 30 minutes is recommended it can vary depending on other factors, such as pH and heat (Oxfam, 2001). If the water has a higher temperature, the chlorine will have shorter contact time. Furthermore, pH increases, the water becomes more basic and the disinfectant capacity of chlorine will decrease. There are several different forms of chlorine one can use, for instance there are liquids and tablets (WHO, 2011). In addition, even household bleach can be suitable for disinfection if it contains high enough values of hypochlorous acid. Water containing more suspended and organic material will need more chlorine to reach acceptable quality (Oxfam, 2001). However, Falk (2018; personal communication) explains that the combination of organic materials and chlorine can create substances which are carcinogenic. Therefore, it is recommended by WHO to have a turbidity less than one nephelometric turbidity unit (Oxfam, 2001). Furthermore, too much chlorine will make the water taste and smell bad which can lead to people not wanting to drink it. It is important that where chlorine is used as a disinfectant, everyone who uses it is well understood with the risk of handling the chemical and can to handle it safely (IFRC, 2008). Despite these disadvantages, chlorine is a good method to ensure high quality drinking water since it reduces the number of bacteria between 3-6 LRV (WHO 2011).

2.5.4 Solar UV-light

Solar Water Disinfection (SODIS), is a method to disinfect drinking water through sunlight. One clear plastic or glass bottle is filled with water and placed in direct sunlight (IFCR, 2008). The principles of it is to combine UV-radiation, oxygen activity together with dissolved oxygen as well as heat (WHO, 2011). Oxfam (2001) explains that to enhance the effect of SODIS half of the bottle can be painted black, the black part will be placed downwards for approximately five hours. However, if the sky is cloudy, IFCR (2008) says that the exposure time need to be the double. Moreover, it is a good thing to centre the exposure to midday in tropical climates because of the suns position during that time. This method will destroy 95 % of the pathogens that can exist in the water (Oxfam, 2001). According to WHO (2011) SODIS has minimum value of 3 LRV and a maximum LRV value of 5+. If the bottle is filled to three-quarters and shaken, the process will go on much faster, after this the rest of the bottle should be filled up and place it in the sun (IFRC, 2008). In addition to this, if the bottle is shaken several times during the exposure, the effect will be even more enhanced.

Figure 10 shows a plastic bottled placed on a reflective corrugated iron sheet, in direct sunlight. The UV Radiation from the sun treats the water inside the bottle.

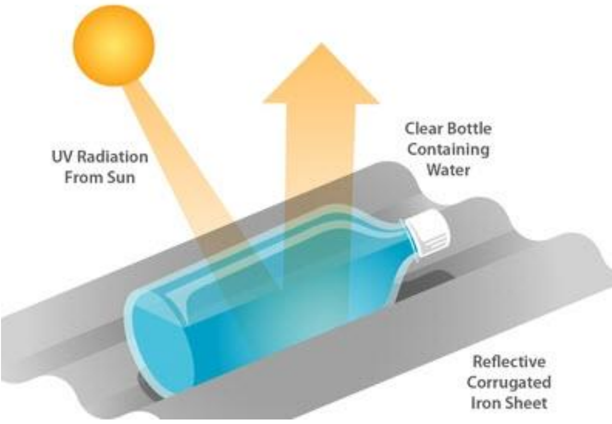


Figure 10 How solar water disinfection works. (National Academy of Science Associate, n.d.). Published with permission.

2.5.5 Boiling

A simple and effective way to kill pathogens and improve the microbial quality of drinking water is to boil it (IFRC, 2008). However, it must be a rolling, bubbling boil for at least one minut, but this is only in flat areas with low topography. At higher altitude the boiling will have to last for at least three minutes because of the difference in temperature and boiling point (IFRC, 2008). According to Falk (2018; Personal communication), there is a problem in areas high up in the mountains because the water will boil at lower temperature and it is crucial to reach 100 °C to inactivate and kill the pathogens. However, Oxfam (2001) encourage people to boil for 20 minutes to be completely sure that all pathogens have been inactivated. But on the other hand, boiling the water for five minutes will kill cholera and Shigella. Moreover, it is recommended to letting the water cool over night before drinking it because of the taste. According to WHO (2008) boiling the water will reduce bacteria's value between 6-9+ LRV. Even though boiling is an easy and good method, IFRC (2008) explains that in areas where wood is scarce it is not suitable since one kilogram of wood work is needed for boiling one litre of water. Another negative aspect can be that the taste of the water will be changed.

2.6 Health Promotion to increase peoples control over their own health

Health Promotion is a generic term with the purpose to increase peoples control over their own health (WHO, 2016). Karolinska Institutet (n.d) states that health promotion often includes campaigns with information and explanations to promote and optimize health potentials, both physical and psychosocial. Health promotion programs are formed to be preventing and to encourage different behaviors (Karolinska Institutet, n.d). According to WHO (n.d), one of the three key elements in Health Promotion is Health literacy. It means that people need to have the necessary knowledge, information and skills to make healthy choices, and the chance to improve their behaviors in a healthy direction. However, there is a complexity when some people don't have the opportunity to make those choices (WHO, 2016). According to Nutbeam (2000), health promotion programs focus should be promoting education and communication in the subject and to prevent diseases together with improvements in contemporary health education strategies.

An important part of a successful health promotion program is to identify different aspects of the culture and traditions in the land where it is being carried out (IFRC, 2008). In addition, it is crucial to combine technical treatments with education about how hygiene and sanitation affects water. To achieve a successful health promotion, it is important that the people taking part of it understands all information otherwise they will not be able to continue the work themselves. To improve the health in areas where health promotion is needed, one must change behaviour. It can be a hard and long procedure to change peoples mind but if the people would have the knowledge in how their health are being affected, IFRC (2008) says that they would be more eager to change. On the other hand, knowledge is not always enough, it is important to encourage people in safe hygiene practice.

IFRC (2008) has created a four-step guide on how to ensure a successful health promotion.

1. Conduct assessment that focuses in water, sanitation and hygiene
2. Select target group
3. Develop hygiene messages
4. Select communication methods

One lecture or opportunity is not enough to ensure good enough health. There need to be some sort of following up on the education, the follow up should support the program material and strategy, and therefore make a larger impact and improve the situation (IFRC, 2008).

3. Material and Method

The students at Rukole Primary School are in the ages between 5–14. The school has seven classrooms and there are often more than 100 students in each room, it is open for the students 260 days per year. The water system at Rukole Primary school consists of two rainwater tanks that are located on their property, see Figure 11. Tank 1 is approximately 46 m^3 but broke in an earthquake 2016 and as a result of this the tank was leaking during the study. Tank 2 is approximately 50 m^3 and about 40 years old, this means that it is almost completely worn out, see Figure 12 (b). Both tanks are provided with water which is collected from the roofs of nearby buildings and lead through pipes to the tanks. For Tank 1, the catchment areas are roof 1 and 2 and the total area is 350 m^2 and for Tank 2, the catchment area is roof 2 with a total area of 175 m^2. These two tanks are supposed to supply the students and the teachers with drinking water every day. The students in total got 5-10 buckets, containing 10 litres each daily during the field study. Meaning that every student then got between 0.4dl and 0.8dl water a day. Since both tanks are locked for distribution there were no possibility for the students to fetch more water when the buckets were emptied. Because of the topography in the district the closest fresh water source was more than 10km away.

In addition, the teachers could collect water from the school to their homes (Twagirayesu, 2018). Four of them lived at the school property, see Figure 11 , and used the tanks at the school as their only water resource. The teachers boiled the water before drinking it, but because there were not enough time or money the teachers didn't boil the water for the students. Therefore, the students drink the water directly from the tanks without any treatment or barriers. The toilets are dry toilets with a hole in the ground, see Figure 11 for location. Next to the toilets there were a few hanging buckets to wash hands, but because of water scarcity they were empty and there was no opportunity for the students to wash their hands.

According to the teacher Twagirayesu (2018-02-12; personal communication), there were about 400 students missing every day because of unknown reasons and during the field study, three students passed away.

Figure 11 Map over Rukole Primary School with surrounding buildings. Map material retrieved from Google Maps.

(a) (b)

Figure 12 Tank 1 (a), Rain water tank above ground at Rukole Primary School. Tank 2 (b), under ground rain water tank.

Figure 13 Building 1, with one of the roofs working as catchment areas for the rain water tank

3.1 Water quality testing on samples from Rukole

To establish the current biological quality of the water at Rukole Primary School test were taken to see the amount of indicator organism in it. The microorganisms in focus were E.coli, total Coliforms and Enterococci because they all indicate that feces can be found in the water.

The tests for E.coli and Coliforms were taken according to the ISO 9308-2:2014 standard. Water was collected in sterile containers of 100 ml each. First reagent, Colilert-18, was added to the water sample and the container was shaken to let the reagent blend with the water. After this the mix was poured into a Quanti-Tray/2000 by IDEXX laboratories, which counts the amount of bacteria from 1-2419. The tray is divided into two parts, one with 48 small wells and another with 49 larger wells. All these should be filled with water before they are incubated at 35 °C during 18 hours. When the 18 hours had passed, the results could be read and calculated. To see how much Coliforms that existed in the sample all yellow wells were calculated and together with the IDEXX Quanti-Tray Most Probable Number -referens table a total number of Coliforms in one 100ml sample could be decided. The same procedure was used to calculate the amount of E.coli but instead of solemnly calculating the yellow wells, the tray was placed under a UV-lamp to see both yellow and fluorescence ones. The same MPN-table was thereafter used to determine the amount of E.coli in the sample.

To calculate the number of Enterococci in the water, the reagent Enterolert*-E, was used instead of Colilert-18. Otherwise the procedure followed the same pattern as for E.coli but with the difference that the test was incubated for 24 hours at a temperature of 41 degrees Celsius. When reading and calculating the results for Enterococci the number of blue fluorescence wells indicated if the test was positive for Enterococci or not. Visible blue fluorescence wells meant that the test was positive for Enterococci. The amount of small as well as large fluorescence wells were counted and compared to the MPN-table as before. Figure 14 shows the principle of how the number of bacteria are read based on the number of large and small wells according to IDEXX Quanti-Tray MPN -referens table. In this examplee, there is one small well and three large ones which means that there is a total of 4.1 bacteria in one sample of 100ml.

Small wells positiv

Large wells positiv

	0	1	2	3	4	5	6
0	> 1	1.0	2.0	3.0	4.0	5.0	6.0
1	1.0	2.0	3.0	4.0	5.0	6.0	7.1
2	2.0	3.0	4.1	5.1	6.1	7.1	8.1
3	3.1	4.1	5.1	6.1	7.2	8.2	9.2
4	4.1	5.1	6.2	7.2	8.3	9.3	10.4
5	5.2	6.3	7.3	8.4	9.4	10.5	11.5

Figure 14 How to read the number of bacteria in a 100ml sample with the IDEXX MPN-table

3.2 Risk assessment and risk management of the water system

In order to get a complete picture of the water system and how the hazards affected it, a risk assessment was done, and a so-called Risk Matrix was created. When the most urgent risks were identified, the next step was a Multi-Criteria Decision Analysis, MCDA, was done to investigate the risk reduction of different solutions as well as consider other aspects such as customer trust, cost and availability. This, to find which solutions that were most appropriate for the school to reduce the most urgent risks in a sustainable way.

3.2.1 Hazards and Hazardous events

First, the water system was divided in to three zones according to Figure 15. The catchment area includes the roof and pipes that lead to the tanks, zone A. The available water storages are the two tanks and they are therefore in zone B. The buckets that are used for distribution of water were in zone C. For every zone, there were hazards, that either contaminated the water or affected the quantity of it, identified. These hazards are presented in Table 4. Furthermore, there were hazardous events connected to every hazard and they were investigated both on-site by visual inspection and during preparation work. Everything from likely to unlikely events were considered during this part of the process. The hazardous events that were identified were very specific to make it easier to decide the probability and consequence of them. In total, there were 23 hazardous events identified, these are presented in Appendix 1, Table a – Table d. The events are named with a letter, A, B or C, depending on which zone it appears in, and a number to get a clear structure of the risk matrixes. The hazardous events that appeared on the water system never affected both quantity and quality. Therefore, one specific risk matrix was done for the quality and one for the quantity.

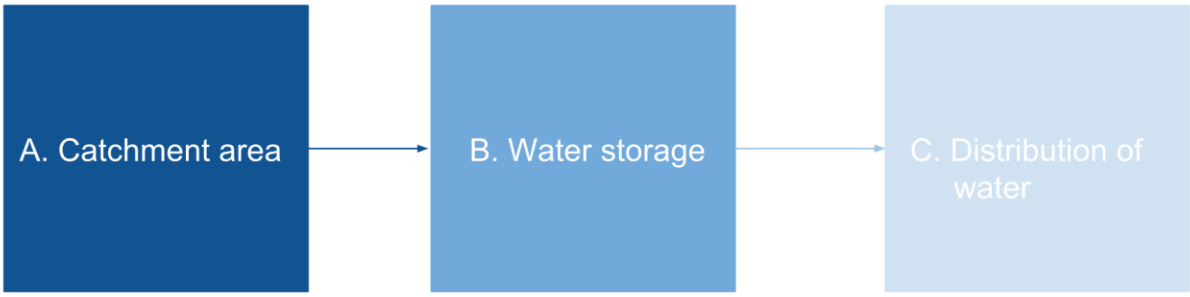


Figure 15, The water system at Rukole Primary school, based on WHO's (2011) system division

Table 4. Hazards for every zone of the water system.

Zone	Description of hazard
A.	The water gets contaminated by the catchment area, or isn't enough to collect water
B.	The water in the storage get contaminated, or isn't enough to collect water
C.	The equipment for distribution get contaminated, or isn't enough

Two of the 22 hazardous events were, *the catchment isn't enough*, and the *tanks are too small for the number of students*. To find out if there were any risk regarding these two some calculations were made. The catchment areas for the two different tanks were measured and the rain water data in the region was retrieved from world weather online (2017), to calculate how much water that theoretically could be collected Equation 1 was used (Thomas & Martinson, 2007). The collected rain data was from 2015-2017 and the average value was used. In tropical areas about 85% of the rain water reaches the tank (Thomas & Martinson, 2007) and therefore, the rain depth is multiplied by 0,85. The calculations were made both for each rain season as well as for one entire year. The result was used to estimate the possibility for the hazardous event regarding enough catchment area.

Equation 1 How to calculate total volume collected water depending on catchment area and rain depth

$$Collected\ Water\ [m^3] = Catchment\ area\ [m^2]\ x\ Rain\ depht\ \ [m]\ x\ 0{,}85$$

To find out the risk if the amount of stored water is too small, calculations of the volume water needed were made according to Equation 2. This result was compared how much water that the school collected for one year as well as the size of the tanks. It was also compared to the amount of distributed water at the school during the field study, see chapter 3.

Equation 2 Total volume of water for one year

$$Water\ \left[\frac{l}{year}\right] = \left(No.of\ students * Distributed\ water\ \frac{l}{day} + No.of\ teachers * 20\ \frac{l}{day}\right) * No.of\ school\ days$$

The teacher at the school use the water for household as well, but the children only use it for drinking and for hygiene. The specific volume needed for the students and the teachers is based on guidelines who are presented in chapter 2.2. The volume that is distributed today is based on the information in chapter 3.

3.2.2 Creating a risk matrix

A risk matrix was made to identify the greatest hazardous events and organize them mathematically to find the greatest risk to the water system. Every event was evaluated and got a specific number, describing the probability for the event to occur. To decide the probability for all hazardous events, observations on site were done. Furthermore, the consequence of each event and how it would affect the school was estimated and graded. The grading and its description were based on the number of students that were sick every day, see chapter 3, and the result from the water quality analysis, see chapter 4.1. In Appendix 1, the numbers and their descriptions are listed. By multiplying the probability for a certain hazardous event with the consequence of the same event a total risk value could be established. For this specific system, it was noticed that the consequence would have a bigger effect on the risk than the probability. For example, if the roof gets contaminated by feces from animals it would contaminate the water that flows to every tank on the school. Even if the probability for the hazard would be reduced and the feces would decrease, it would still reach the tanks, and the affect would be large because of the bacteria's ability to grow in water. Therefore, the risk would still affect the whole school majorly. This is shown in Table 5 where the grading has an exponential scale were the consequence increases more than possibility.

In which zone, A, B or C, of the water system the hazardous event appeared were important to decide the consequence. If the hazardous event appeared in zone A or B, where the storage tanks got affected the consequence was high. However, if the hazardous event only appeared in zone C, where the distribution got affected the consequence was not as high since less people would be involved. For example, if some of the students used their own bottles for getting water they were not affected by dirty buckets used for distribution.

Table 5 *Grading of possibility and consequence for the water system*

Probability		Consequence	
Scale	**Description**	**Scale**	**Description**
16	Once per day	81	Major impact for the whole school
8	Once per week	27	Major impact for some of the students/teachers
4	Once per month	9	Minor impact for the whole school
2	Once per year	3	Minor impact for some of the students/teachers
1	Once every five year or more	1	Insignificant or not detectable

Probability	Consequence: Insignificant or not detectable- Rating 1	Minor impact for some students/teachers- Rating 3	Minor impact for the whole school- Rating 9	Major impact for some students/teachers- Rating 27	Major impact for the whole school- Rating 81
Almost certain/once a day- Rating 16	16	48	144	432	1296
Likely/once a week - Rating 8	8	24	72	216	648
Moderate/once a month- Rating 4	4	12	36	108	324
Unlikely/once year- Rating 2	2	6	18	54	162
Rare/once every 5 year- Rating 1	1	3	9	27	81

Risk score / Risk rating	< 24	24-81	81-162	> 162
	Low	Medium	High	Very High

Figure 16 Risk matrix, green indicate acceptable risks, yellow is the ALARP-region and red indicate unacceptable risks.

As shown in Figure 16, the risks below the rating 24 are considered acceptable while a risk rating score between 24 and 162 is considered “As Low as Reasonable Practicable” and is in the yellow zone of the risk matrix. In the red zone are all risks above the risk rating 162 and they are unacceptable. The description of the scale for possibility and consequence as well as the model for the risk matrix were chosen based on WHO’s (2009) system division and adapted to suit the water system at Rukole.

3.3 Multi-Criteria Decision Analysis

To reduce the risks that were identified during the risk analyse, different solutions were evaluated together with every hazard. In total, 16 different solutions were presented for Rukole Primary school, see Table 6 and Table 7. Thirteen out of these were presented as suitable to improve the quality of water system at Rukole Primary School, see Table 6. The three solutions in Table 7 improved the hazardous events regarding quantity. One solution reduced either the consequence or the probability of the hazardous events. However, if the solutions were combined both consequence and probability could be reduced for each risk.

To find out which solutions that were the most suitable and sustainable for the school, four different factors were considered in the MCDA, based on what was important in the area.

- Risk reduction
- Availability
- Cost estimation
- Costumer trust for the solution

One MCDA was made for the quality risks and one for the quantity risks. The solutions to improve the quantity were decided to be financed by donors since the school couldn’t afford them in the near time and the ones regarding quality where supposed to be financed by the school itself.

Table 6 Thirteen different suggested solutions to improve the water quality

Solution no.	Description of solution
1	Solar Water Disinfection, SODIS
2	Slow sandfilter
3	Ceramic filter
4	Chlorination
5	Fabric filter
6	Boiling
7	Education about water, sanitation and hygiene
8	Install a First flush system
9	Install a pump and tap
10	New bucket, sealed with tap
11	Clean the catchment area
12	Clean the buckets before using them
13	Clean the hands after toilette with soap

Table 7 Three different suggested solutions to improve the water quantity

Solution no.	Description of solution
14	Build a new tank
15	Repair the tanks
16	Lead more pipes from more roofs

3.3.1 Risk reduction

The 16 solutions were analysed both combined as well as alone to find out the risk reduction. The risk reduction, ΔR, is the difference between the risk of the hazard minus the risk of the hazard when a solution is implemented, an example of this is illustrated in Table 8. To get unambiguous a result in the MCDA a normalisation of the risk reduction was calculated according to Equation 3. Every solution got a value between 0-1 which also was related to the other solutions. The normalisations values are illustrated in Table 9 to understand the relation between the solutions.

Equation 3. Calculates the normalisation for risk reduction

$$n_1 = \frac{\Delta R \; for \; solution \; nr \; x}{the \; greatest \; \Delta R}$$

During the field study the reduction of some of the technical solutions were evaluated. For instance, a small pilot of SODIS was carried out. The water quality was tested according to section 3.3, tests were taken before the bottles had been exposed to the sun and after they had been in the sun for 2 days. This showed what the actual risk reduction became for the solution SODIS, this was used to determine how effective the solution was.

For the quantity, it was planned how big a new tank need to be to reduce the risk that occurs because of the hazard *the storage is not enough*. This was done by investigate different tanks that was built in the area to see what was possible and the advantage and disadvantage of different tanks. The investigation also included planning about the location of the tank, decide catchment area and so on. It was also investigated how much the risk for the hazard *the catchment area is not enough*, would be reduced by doing the catchment area bigger for the existing tanks in the aim to collect more water during rain falls. To do this it was necessary to find out how much the catchment area could increase.

Table 8 Shows the probability, P and consequence, C without any solution and also probability, P' and consequence, C' after the solution. The risk is filled with the colour which represent the place in the risk matrix.

Hazardous event	Solution	P	P'	C	C'	R	R'	ΔR
No. 1	No. 1	8	1	27	27	216	27	189
	No. 3	8	8	27	1	216	8	208
	No. 1 and 3	8	1	27	1	216	1	215

Table 9 Shows the normalisation of the risk reduction

Solution for hazardous event 3	ΔR	Normalisation, n_1
Solution no. 1	189	0,879
Solution no. 2	208	0,97
Solution no. 3	215	0,1

3.3.2 Cost estimate

The reason for performing a cost estimate- criteria in the MCDA was because the economy in the region is dreadful and the aim was to present the most appropriate solution for the school, hence it need to be affordable for the school. However, for the solutions regarding quantity it was decided that they would be financed by donors instead. As a result, the cost estimation for these solutions were not as important in the MCDA even though it mattered for the donors.

The price of local material needed for the solutions were investigated and documented. Some of the solutions were made of material that couldn't be found in the area and the cost for these were decided by finding out what similar objects cost.

To use the cost in the MCDA a normalisation was done on the cost estimation, according Equation 4. Table 10 shows an example of how it can be done.

Equation 4 Calculates normalisation for cost estimate

$$n_2 = \frac{Highest\ cost - cost\ for\ solution\ nr\ x}{Highest\ cost}$$

Table 10 Calculates the normalisation of cost

Solution for hazard no. 3	Cost Estimation	Normalise, n_2
Solution no.1	30	0,7
Solution no.2	50	0,5
Solution no.3	100	0

3.3.3 Costumer trust for the solutions

Trust for the different solutions were important to ensure that the solutions would be maintained if they would be implemented. Conversations and workshops with the teachers and the manager of Mavuno as well as local people, like workers at Mavuno and parents to the children etc. were carried out to find out what they believed about the different solutions. To increase the costumer trust for different solutions, education about water, sanitation and hygiene, could be carried out but education alone didn't reduce any risk. In addition, the literature study about earlier projects in Karagwe, see chapter 2.4 and section 2.5.1, helped to find out what kind of solutions that were accepted and maintained by the local people.

Examples of different questions that were in focus during workshops, discussions in the project group and the literature study:

- Has anyone in the region used this kind of solutions before and how was it maintained? If so, was it fixed if it broke and was the solution successful?
- Have the concerned heard about the solution before? What is the first thought about the solution, does it seem good/bad/complicated?
- Is the solution reasonable for the school considering the number of students?
- Is the solution time consuming? Is it needing of maintains? Is it needed of one person responsible or is it possible for the students to maintain?
- Is the solution used in developing regions before?
- Is the project group convinced with respect to the situation and regarding the solution?

The information that was shared during workshops and discussions, was the foundation for how the customer trust- criteria was graded in the Multi Criteria Decision Analysis. Figure 17 visualises the grading used in the risk matrix. When the different solutions had been graded, the normalisation was done so the criteria could be used in the MCDA according to Equation 5 and Table 11.

Equation 5 Calculates the normalisation for Costumer trust for the solutions

$$n_3 = \frac{Costumer\ trust\ for\ solution\ nr\ x}{The\ greatest\ Costumer\ trust}$$

Since it was decided that the solution for the quantity would be financed by donors it was even more important that the costumer trust for it was high. That is because it was important to implement something that the school felt ownership over and would take care of when the project ended. To ensure that this was the case a discussion with the school was made to decide if they wanted the solution and what they could provide with in order to implement it, for example, material and some labour.

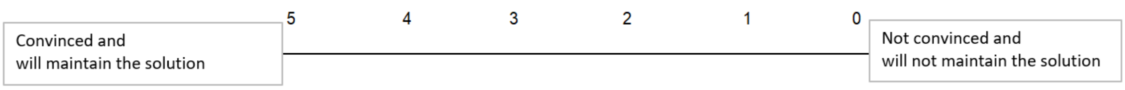


Figure 17 Grading of customer trust and attitude towards maintenance

Table 11 Normalisation of Costumer trust for the solutions

Solution for hazardous event 2	Costumer trust	Normalisation, n_3
Solution no.1	4	1
Solution no.2	1	0,25
Solution no.3	2	0,5

3.3.4 Availability of material for the suggested solutions

To estimate the availability of different material for the suggested solutions an inventory in Rukole village, nearby villages and larger cities in the north of Tanzania was made. As well as that, the availability of material online was investigated. After the inventory and investigation, the availability criteria were graded according to Table 12, and normalised with Equation *6*.

Equation 6 Calculates the normalisation for availibility for the solutions

$$n_4 = \frac{Availability\ of\ solution\ no.x}{The\ nearest\ availablity}$$

Table 12 Availability of material for the suggested solutions

Availability	n_4
Can be found in their homes	1
Can be found in Rukole village	0,8
Can be found in villages nearby	0,6
Can be found in the nearest city	0,4
Can be ordered	0,2
Can’t be ordered	0

3.3.5 Ranking of the criteria's in the MCDA

A ranking of the criteria was made to present the importance of them with regard to each other. The different criteria were ranked with a number between 0-1 and the total of all numbers were 1. Since the solution to improve the quantity was decided to be financed by donors the cost estimation wasn't ranked as high. On the other hand, the costumer trust for the solution were ranked higher because the school needed to feel ownership for these solutions. The total number of the ranking among these four had to be one. Table 13 shows how the criteria for quantity were ranked. For the quality, the four criteria were ranked the same, see Table 14.

The result of the MCDA was presented after multiplying the normalisation for risk reduction (1), cost estimation (2), costumer trust (3) and availability (4) for every solution and for a specific hazardous event according to Equation 7.

Equation 7 Calculates the total value for every solution for one specific hazardous event

$$Total = n_{i1} * w_{i1} + \ n_{i2} * w_{i2} + n_{i3} * w_{i3} + * \, w_{i4} n_{i4}$$

This gave a number between 0-1 for each solution and the one with the highest number was the most suitable one for the water system at Rukole Primary School.

Table 13 Criterias for quantity

Criterias	Ranking, w_i
1.Risk reduction	0,3
2. Cost Estimation	0,1
3. Costumer Trust	0,4
4. Availability	0,2

Table 14 Criterias for quality

Criterias	Ranking, w_i
1.Risk reduction	0,25
2.Cost Estimation	0,25
3.Costumer Trust	0,25
4-Availabality	0,25

3.4 Arrangement of education

During the first week of the field study two workshops were held with the teachers. It contained of questions to the teachers about water, hygiene and sanitation and how the school work with it and what they teach about the subject today. The questions in the workshop were open and formed to make the teachers think for themselves more than give them the answer or lead them in any direction. During the workshops, the teachers were divided into four different groups of 4-5 people each to discuss four questions and write down their answers. These questions were

- Where does the dirt in the water comes from?
- How does hygiene affect the water and the quality?
- What do you learn the student about hygiene today and how it can be better?
- What do you think could prevent the contaminations?

For more details about the workshops, see Appendix 4. The smaller group discussions were followed by discussion and conclusions together in the big group, led by the project team. The aim of the workshop was to get the teachers inspired and together with them plan the education for the students.

After the workshop, the planning of the education for the students was done. It included observing and talking to different people from different areas, in the aim to match the culture and the interests the best and to find out what the motivation or lack of motivation comes from. The project group also visited homes to some of the students to interview and observe their behavior, motivation and knowledge about the subject. After the investigation and observations, an adaption to the existing situation was made and the education material started to be formed. The educations material was inspired by different strategies about health promotion in chapter 2.6. The structure, time plan and lecture material were designed together with two teachers at the school, who later became responsible for the lessons with the students.

4. Results

During the field study, results from both water quality samplings and calculations of water quantity were reached. As well as that, the risk matrix presented results regarding the most urgent risks at Rukole Primary School, both with regard to quality, quantity as well as different risk reduction factors. During this chapter, these results will be presented.

4.1 Water quality samples

Following tables show how the quality of the water at Rukole Primary School in terms of different amount of the indicator organisms, E.coli, total Coliforms and Enterococci. Based on the number of calculated wells in the fifth column in Table 15, the number of total Enterococci is presented in the sixth column. This is the value which in comparison with guidelines shows if the quality is adequate or not. As Table 15 shows there are a great number of Enterococci in both of the tanks at Rukole Primary School. According to the Tanzanian Guidelines for drinking water, both tanks distribute water that is classified as unsatisfactory. Moreover, both tanks are considered to contain unserviceable water according to Swedish standards. In Table 16, the total number of E.coli is presented in column six and for Coliform the total number is presented in column eight. Tank 1 has less bacteria per sample both when it comes to E-coli and Coliform bacteria as well as for Enterococci, compared to Tank 2.

Table 15 Amount of Enterococci in the drinking water at Rukole Primary School

Tank	Date	Start	Finish	Positive Wells (large/small)	Total number of Enterococci in sample
1	2018-02-26 to 2018-02-27	14.00	14.00	11/45	**139.6**
1	2018-02-26 to 2018-02-27	14.00	14.00	15/47	**191.8**
2	2018-03-10 to 2018-03-11	11.45	11.45	48/28	**396.8**
2	2018-03-10 to 2018-03-11	11.45	11.45	48/42	**755.6**

Table 16 Amount of E.coli and Coliform

Tank	Date	Start	Finish	Positive wells, E.coli (large/small)	Total no. of E.coli in sample	Positive wells, Coliform. (large/small	Total no. Coliform in sample
1	2018-02-13 to 2018-02-14	15.22	08.22	-	-	25/1	**26,6**
1	2018-03-20 to 2018-03-21	15.30	08.30	1/5	6	8/12	**21,8**
1	2018-04-26 to 2018-04-27	15.30	08.30	4/10	16,6	5/8	**13,7**
2	2018-02-13 to 2018-02-14	15.22	08.22	-	-	49/48	> **2419**
2	2018-03-20 to 2018-03-21	15.30	08.30	6/17	24,7	49/48	>**2419**
2	2018-04-26 to 2018-04-27	15.30	08.30	29/17	69,8	49/48	**> 2419**

4.2 Risk Assessment and management

The risk assessment and management for this project identified the most urgent risks for the water system at Rukole Primary school, it also helped to decide which solutions that were the most suitable and sustainable for the school, and which later were implemented.

4.2.1 Hazardous events with the most urgent risk

Following, the hazardous events that causes the most urgent risks are presented. The hazardous events are also illustrated in the risk matrix in Figure 18. The rest of the hazardous event are presented in Appendix 1 in Table a – Table d, and all the risks are presented in Figure a.

- A1 - Feces from animals on the catchment area get in contact with the water that reaches the tank
- B3 - Buckets for collecting water places in feces reaches the water in the tank
- B7 - Feces from animals leaks in through the roof of the tank
- C2 - Hands contaminate the water and the buckets for distribution
- A10 - The catchment area is not enough during rain falls
- B8 - The tank leaks
- B10 - The number of students is to high compare to the size of the tanks

As showed in the Figure 18, the event that causes the most urgent risk for the quality is B3. The event has both the highest probability and consequence, which means that it happens every day and has a major impact for the whole school. The second and third most urgent risks for the quality are A1 respectively B7. As seen in Figure 18, the events have the same consequence as B3, but the probability is lower. The fourth event that causes an urgent risk is C1. The consequence for the event is lower than B3 and only affect some of the students and teachers majorly.

The most urgent risk for the quantity is caused by B10. During one year, the school will need about 1000 m^3 water, which is calculated according to Equation 2. However, today the school is provided with 280 m^3 calculated with the same equation, which means that it's not enough, see Appendix 1 and Equation a and Equation b for calculations. This result is the foundation of the chosen consequence and probability for the hazardous event B10.

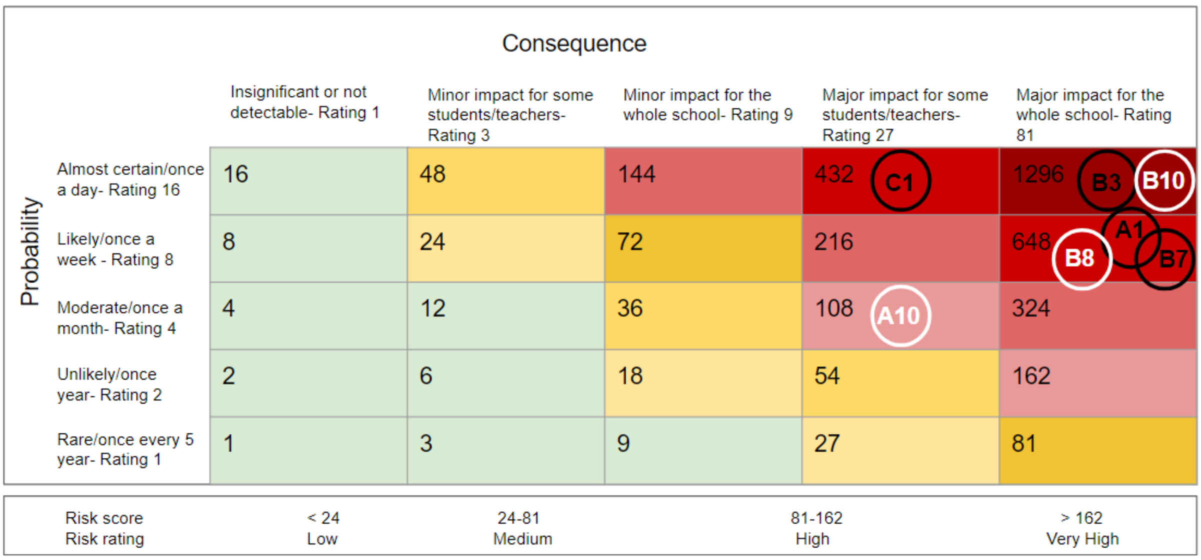


Figure 18 The black circles illustrate the hazardous events regarding quality and the white circles illustrates the hazardous events regarding quantity.

The second most urgent risk for the quantity is B8 which is showed in the Figure 18.
A10 is the third most urgent risk. During the both rain seasons, it is only in November, when Tank 1 gets filled, see Appendix 3 and Table r. To fill up Tank 2, it normally takes three months while it takes one and a half month to fill up Tank 1 see Appendix 3 and Table o and Table s. During smaller rain falls the catchment area is not enough and the total volume of water that will be collected from June- September is only 52 m^3 Appendix 3 and Table q. The total calculated volume that can be collected with the existing catchment areas is 400 m^3, for more detailed calculations see Appendix 3 and Table j.

4.2.1 Risk Reduction

The following chapter will introduce the risk reduction for some of the best solutions as well as some of the solutions that seemed appropriate for the specific hazardous event and for Rukole Primary School. Figure 19, shows two hazards regarding quality, A1 and B7, how the risk decreases, ΔR, with four different solutions. SODIS + Fabric filter, Boil, Clean the catchment area + Install a first flush, and Repair the tank. ΔR for these solutions are illustrated with different lines, presented in the left, upper corner.

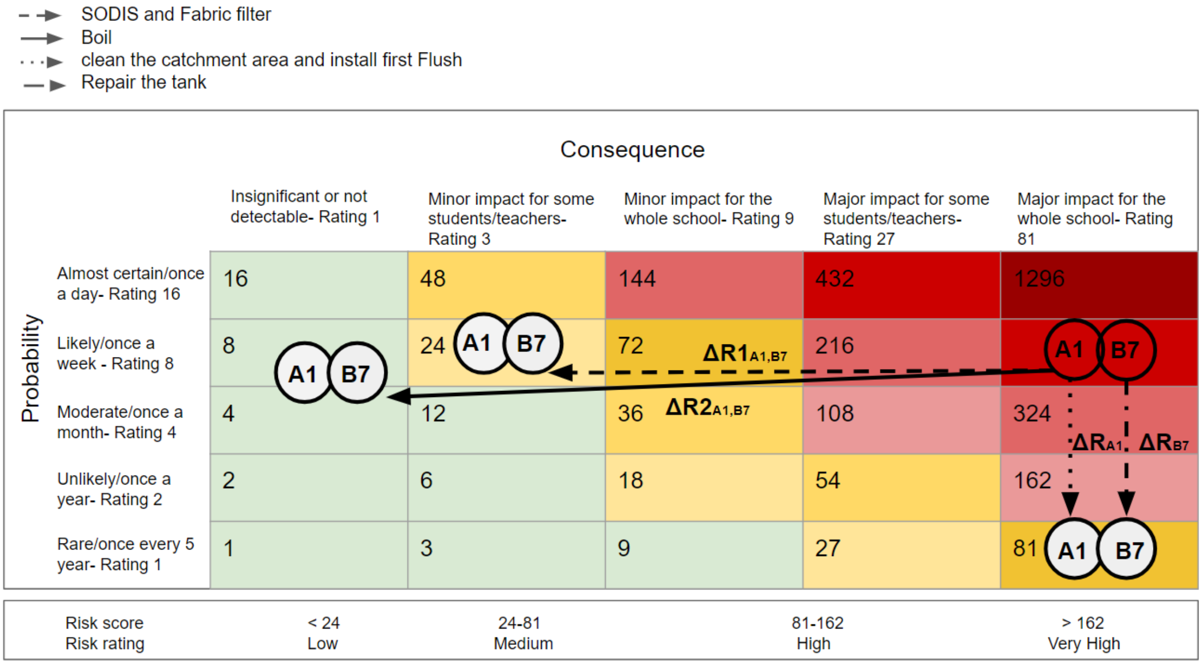


Figure 19 Risk Matrix with risk reduction for hazardous events, A1 and B7.

Table 17 Risk reduction for A1

Risk reduction for A1	*ΔR*	Normalisation, n_1
$\Delta R1_{A1,B1}$	624	0,98
$\Delta R2_{A1,B1}$	640	1,00
ΔR_{A1}	567	0,89

Table 18 Risk reduction for B7

Risk reduction for B7	*ΔR*	Normalisation, n_1
$\Delta R1_{A1,B1}$	624	0,98
$\Delta R2_{A1,B1}$	640	1,00
ΔR_{B7}	567	0,89

As seen in the Figure 19 and the Table 17 the greatest risk reduction, ΔR, for A1 and B7 is through boiling. Boiling the water make the risk accepteble which is illustrated in the figure. SODIS and Fabric filter is also a big risk reduction, but still, it is a risk that the water will affect some of the students and teachers minorly.

To prevent the contamination on the catchment area to reach the water, it is seen in the Figure 19 and Table 18 that the best way was to clean the catchment area as well as install a first flush on the existing tanks. The same thing is for repairing the existing tank, the contamination will not reach the water in the tank and the posibility is decreased.

Figure 20 shows C1 and B3 and how the risk decreases, ΔR with the four different solutions, Install a pump and a tap, Wash hands, Boil and, Boil + install a pump and a tap. The ΔR of the solutions are illustrated with different lines and are presented in the left, upper corner.

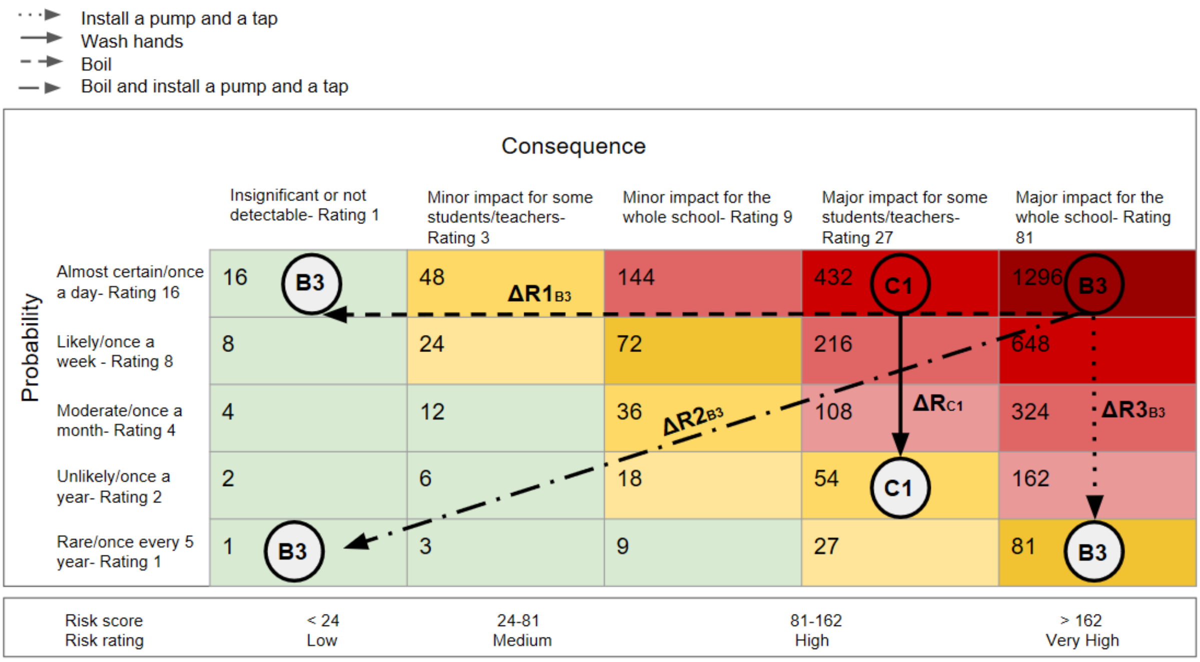


Figure 20 Risk matrix with risk reduction for hazardous events, C1 and B3.

Table 19 Risk reduction for C1

Risk reduction for C1	ΔR	Normalisation, n_1
ΔR_{C1}	378	0,90

Table 20 Risk reduction for B3

Risk reduction for B3	ΔR	Normalisation, n_1
$\Delta R1_{B3}$	1215	0,95
$\Delta R2_{B3}$	1295	1,00
$\Delta R3_{B3}$	1280	0,99

To install a pump with tap and also boil the water is the best solution for B3, which is seen in Figure 20 and Table 19. To install a pump and a tap will only make the possibility lower, and to boil the water will only reduce the consequence. As seen in the risk matrix in Figure 20 the risk after boiling will be in the green area, which indicates that the risk is insignificant.

For the hazardous event, C1, one solution is to wash hands before drinking water. Even though the water will be treated in other ways, like boiling, there is a risk that the contaminated hands will reach the water. The solution will decrease the possibility, but the consequence will be the same, which puts the risk in the ALARP region in the risk matrix in Figure 20.

Figure 21, shows A10, B8 and B10, and how the risks decreases with the four different solutions, Repair the existing tanks, Lead more pipes from more roofs to the existing tanks, *Build a new tank* and, *Build a new tank + repair the old ones*. The ΔR for the solutions are illustrated with different lines and are presented in the left, upper corner.

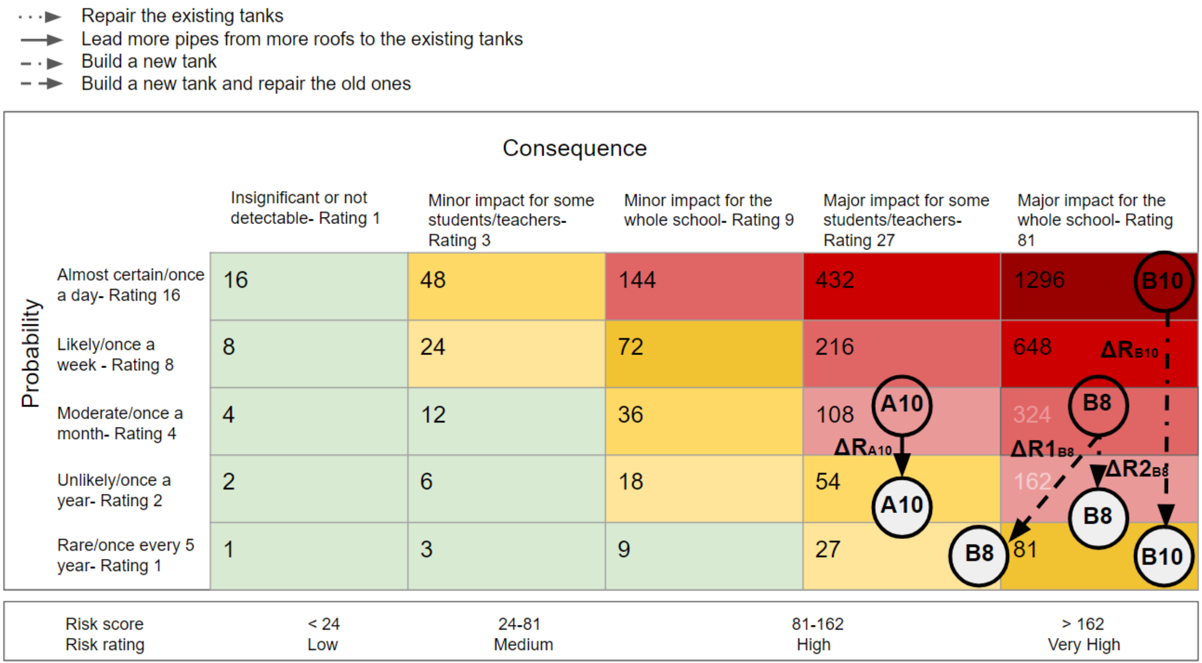


Figure 21 Risk matrix with risk reduction for hazardous events, A10 and B8.

Table 21 Risk reduction for A10

Risk reduction for A10	*ΔR*	Normalisation, n_1
***ΔR**A10*	54	1,00

Table 22 Risk reduction for B8

Risk reduction for B8	*ΔR*	Normalisation, n_1
***ΔR1**B8*	297	1,00
***ΔR2**B8*	162	0,55

Table 23 Risk reduction for B10

Risk reduction for B10	*ΔR*	Normalisation, n_1
***ΔR**B10*	1215	1,00

A new tank together with enough catchment area for the tank will ensure that the school can collect enough water. In the risk matrix it is showed that a new tank will make the risk for the hazardous event, B10. in the ALARP region, in Figure 21.

Today the catchment area is not enough. It is possible to increase the catchment area with 175 m^2. This will reduce the risk with 54, as seen in the risk matrix in Figure 21. In Appendix 3 and Table k, it is calculated the total amount of collected water if the catchment area has increase.

For the hazardous event, B8, there are two solutions that will reduce the risk, *repair the tank*, which reduced the probability and the second one is, *repair the existing tank + build a new tank* which together both reduced the consequence and possibility, showed in Figure 21.

4.3.2 Cost estimation, Availability and Costumer trust

The three other criteria, Cost Estimation, Availability and Costumer trust are presented in this following chapter.

For the hazardous events, A1, B3 and B7, *Boil* were one of the presented solutions. It has a high risk reduction but the costumer trust for the solution was not enough. With Education about boiling the costumer trust was graded higher and hence the total result was higher. The same result appeared when education was combined with the solutions, *SODIS and fabric filter*, and *Wash hands,* the costumer trust increased as well as the total risk reduction. This means that the trust for the different solutions would increase if education were held, and the school would be more convinced and therefore maintain the solution. This is showed in Table 24 - Table 27.

For the solution, *Install First Flush*, in Table 24, *Repair the existing tanks* in Table 25 *Install a pump and tap* in Table 26 and *Lead more pipes from more roofs to the existing tanks* in Table 28, the costumer trust was graded low. The solutions, *install a pump and tap,* and *repair the existing tanks* were expensive and the availability was low.

Build a new tank, had a high total value and it was the only solution for the hazardous event.

Table 24 - Table 27 shows the graded values regarding quality, and Table 28 - Table 30 shows the graded values regarding quantity.

Table 24 Cost, Costumer trust and availability for the hazardous event A1

Solutions for A1	*Cost [USD]*	Costumer Trust	Availability	Total
SODIS and Fabric filter	62	2	0,8	0,78
Boil	45	3,5	0,8	0,89
Clean catchment areas + install First Flush	120	3	0,6	0,70
Education + Boil	45	5	0,8	0,96
Education + SODIS and Fabric filter	62	4	0,6	0,88

Table 25 Cost, Costumer trust and availability for the hazardous event B7

Solutions for B7	*Cost [USD]*	Costumer Trust	Availability	Total
SODIS and Fabric filter	62	2	0,8	0,83
Boil	45	3,5	0,8	0,92

Repair the existing tanks	1 500	2	0,2	0,51
Education + Boil	45	5	0,8	0,99
Education + SODIS and Fabric filter	62	4	0,6	0,93

Table 26 Cost, Costumer trust and availability for the hazardous event B3

Solutions for B3	*Cost [USD]*	Costumer Trust	Availability	Total
Install a pump and a tap	300	3	0,2	0,73
Boil	45	3,5	0,8	0,83
Boil + Install a pump and a tap	345	3	0,2	0,45
Education + Boil	45	5	0,8	0,91

Table 27 Cost, Costumer trust and availability for the hazardous event C1

Solutions for C1	*Cost [USD]*	Costumer Trust	Availability	Total
Wash hands	10	3	0,8	0,83
Education + Wash hands	10	5	0,8	0,96

Quantity

Table 28 Cost, Costumer trust and availability for the hazardous event A10

Solutions for A10	*Cost [USD]*	Costumer Trust	Availibility	Total
Lead more pipes from more roofs to the existing tanks	200	3	0,5	1

Table 29 Cost, Costumer trust and availability for the hazardous event B8

Solutions for B8	*Cost [USD]*	Costumer Trust	Availability	Total
Repair the existing tanks	1 500	2	0,2	0,69
Build a new tank + Repair the existing tanks	11 500	4	0,2	0,74

Table 30 Cost, Costumer trust and availability for the hazardous event B10

Solutions for B10	*Cost [USD]*	Costumer Trust	Availability	Total
Build a new tank	10 000	5	0,2	1

4.2.2 The most appropriate and sustainable solutions

Even though the presented solutions all are good, there are only seven considered appropriate and sustainable for Rukole Primary School. These are:

- Boiling
- Education about water, sanitation and hygiene
- Install a first flush system
- Install a pump and tap
- Clean catchment areas
- Wash hands
- Build a new tank

4.3 Implementation of solutions

Four of the solutions were implemented at Rukole Primary School in order to improve the water situation. These solutions were, *Build a new tank*, *Educate the students in water, sanitation and hygiene* and in addition, *Education about water boiling* as well as *Solar Water Disinfection.*

4.3.1 Education about water, hygiene and sanitation

The result of the arrangement of the education described in the method, provided the project with material and preparations for the lessons. The education contained of the most important parts to know about water, hygiene and sanitation. It included the two most basic treatments steps easy to practice at home, boil and SODIS, and how to keep the water clean and safe after treating it. The main aim with the lesson was to inform the student so they can inspire and spread the word to their friends and families. The lessons were formed in different ways according to the age of the students and held in Swahili.

Once a week, one lesson was held with one class. It started with experiments to make the students interested, followed by group discussions and then speaking in whole class. The teacher informed the students about the context and the importance of hygiene, water and sanitation, see Appendix 4 for details. In class, the students were told to write down the information from the black board to bring at home and they were also invited to play theater in front of the class to learn the other students how to clean their hands in a proper way, for example. The students were told what happens when they drink dirty water and how they can prevent getting sick. They were learned about basic treatment steps and how to practice them by themselves at home, to improve the water quality. In the end of the class they were given a homework for next week. The homework encouraged the practice of the different treatments step at home and to tell their families about what they learned at the lesson, how to clean hands and what can happen if you don't boil the water before drinking it. The students were told that they will meet again next week for a follow-up lesson and to get a certificate for their participation.

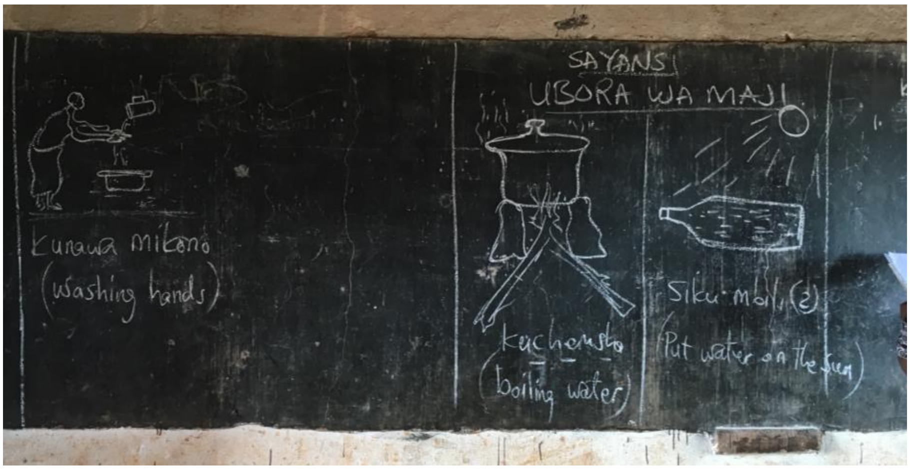


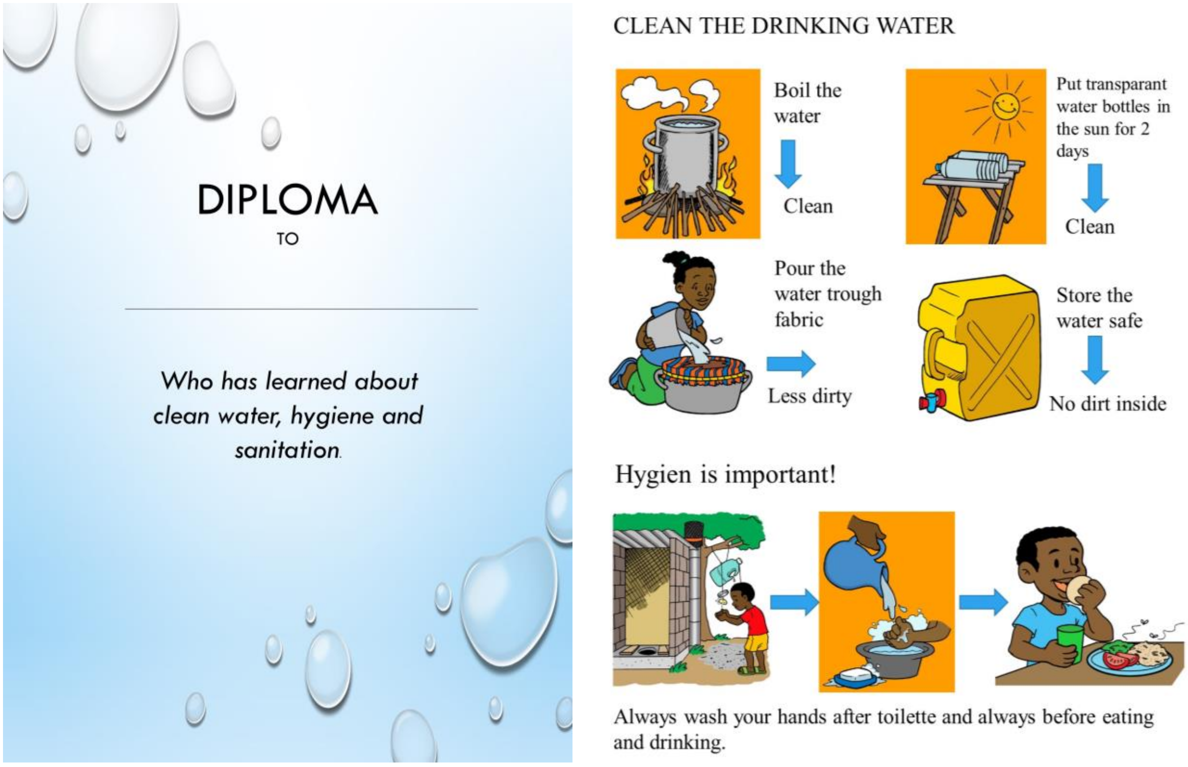
Figure 22 The black board during one lesson about water, hygiene and sanitation.

One week later the same class had a follow-up-lesson. The teacher divided the class in groups and asked them:

- How did it go to practice the treatment step at home?
- How did you show your family what you learned?
- What was the respond from your family?
- How will you continue to use this knowledge?

Group discussions and sharing experiences from the discussions with their families were held, see Appendix 4, for details. Together with the teachers, they investigate what kind of solutions that worked and if some of them were more difficult to practice than others. The students were told to repeat what they remembered and what they learned, and which kind of tips they can teach each other to remember and how to spread the knowledge in the best way. In the end of the lesson the students were given a diploma, for learning and participate.

On the backside of the diploma, see Figure 23 (b), the most important information is showed. The diploma supports the specific goal with the education that is to reach the students but even the families and parents of the students, to spread and inform the importance of water quality, hygiene and sanitation to the locals in the area.



(a) (b)

Figure 23 The Diploma (a), and the backside of the diploma with information (b). Pictures in (b) are taken from CAWST (n.d).

Figure 24 One class after completed education, showing theirs diplomas.

4.3.2 Implementation of technical solutions

The school is suffering from severe water scarcity and one important solution to solve this was to construct a new rain water tank, to provide the school with the possibility to store more water after rain season. The construction started in the middle of April 2018 and is planned to be finished in the middle of May. The tank was financed by companies and private donors, see picture Figure 25.

The new tank is an over ground tank that can contain 90 m^3, it is located behind the two buildings, 3 and 4, see Figure 11. The tank has a tap in the bottom that will have a natural pressure from the water above. It is a risk that contaminations reached the tank through the catchment area, therefore, a first flush system was implemented. Total catchment area will be 875 m^2 that will provide with about 700 m^3 collected water per year, according to Equation 1, and the total amount of collected water will be about 1100 m^3, see Appendix 3 and Table j.

To ensure that the tank would be welcomed and maintained, Rukole Primary School provided the construction with local material, such as aggregate and sand. The school also helped to prepare the site as well as provided the constructers with food, and the rest was financed by donors. Mavuno ordered the material and was responsible for the construction of the new rain water tank.

Figure 25 Picture taken in May 2018, from the construction of the new tank

5. Discussion

Working in project always bring some difficulties, things change, and plans must be reconsidered. When it comes to working in development regions it is a problem since it’s hard to communicate with the people on site. The preparations before a project suffers and are not always accurate. The internet reception is bad, and it is not a part of the daily routine to check and answer on e-mails. Most of the preparations done in Sweden before the field study were therefore only based on hypothesis. The only criteria towards Mavuno before the project started was that this project should be performed at a school with a working rain water thank with teachers that could speak English. During the first visit to the school, while on site in Tanzania, it was clear that neither a working tank existed, or the teachers could speak good English.

At first the aim of the project was only to purify water with technical solutions and education, but because of the unexpected situation the aim changed. There is no possibility to purify water that doesn’t exist, in order to have high quality water one first must make sure there is enough water, the quantity is crucial. If this would have been clear before reaching Tanzania a lot of changes in the preparation could have been made, for instance the founding process of a new tank could have started earlier which would have been beneficial for the school.

5.1 Deviations in the field study

A problem in the water quality testing process was the fact that the tests needed to be in an incubator for 18-24 hours and in the district of Karagwe there are a lot of power failure. Because of this the incubator was turned off at several times during the testing without knowing at what time it occurred. This will affect the result because slow growing strains may show as negative if the results are read before minimum incubation time but would generate a positive result if the incubation was conducted correctly. Even though this happened a few times during the field study, the results are still presented. The reason for this is because the visual examination on site could confirm that the water system is bad, and the handling of drinking water, sanitation and hygiene is even worse. In addition to this a comparison of the result was made to earlier results made in the same area which could validate the reasonability of the results.

Another deviation is that the risk assessment that was made, was based on the project groups own interpretations of the situation. This means that if the project would be done by someone else on another water system, the result would be different. For example, the cost estimation for the solutions might not be completely correct since some of the material couldn’t be found on the market in the nearby village. Therefore, some of the prices are only estimated without any validation on site. However, there were discussions during the process whether the prices are reasonable, and they were also compared to each other to get a feeling of if they seem appropriate. The same was for the availability, if the material couldn’t be found then local people had to suggest where to find it. Based on this the grading was made with the reservation that the information wasn’t completely true.

The second example is when estimating the customer trust, there were problems related to the culture and communication. It was a deviation and difficulty through the whole project to confirm the truth of peoples’ statements because it is common that people only answer what they think will please the person asking the questions. Because of this, the opinions of Charles Bahati, the project manager at Mavuno, was decisive in many cases. He has great experience from earlier project and knows what has or hasn’t worked before. However, Mr. Bahati is only one person and his opinions are not necessarily representative for the entire population which could affect how the grading for “customer trust for the solutions” was made.

5.2 Difficulties with working in development regions

Even though the quantity is the most urgent problem at the school, the quality of the water is still important in a health point of view. There is a difficulty in creating a balance between these two, which have been a problem during the whole project. However, there are a lot of solutions to improve the quality right away but there is no need for this if people still don't know how their hygiene and maintenance of the water affects the quality. It was a struggle to not handle to impulsive to improve the water quality, the solutions would risk only being a quick fix which in a couple of years or even months wouldn't be used if the understanding of them were low and mistrusted. Since this project strive to be sustainable and have long term benefits these solutions were not implemented.

Before the field study people warned that Tanzania is a post-colonial country which can make it troublesome for a white person to come and change something or bring knowledge they think is needed. Cultural heritage affects how people see each other, both positive and negative. However, in this region it has occurred that people believe that white people have more knowledge than in reality. In some ways, people tried to take advantage of the situation. Even though this happened frequently during the field study, the post-colonial heritage affected the results of the project in a rather good way. Teachers always made time in their schedule for unexpected visits, workshops and discussions. It was somewhat surprising how interested and welcoming they were towards the implementing of solutions. This perception might be misjudging because the solutions could seem better than they were based on their reactions. If the project would have been performed at a Swedish school the result probably wouldn't have formed and developed this quickly.

5.3 Discussion of risk assessment

All the hazardous events that were identified in the risk matrix were not further analysed in the MCDA. Several hazardous events for one hazard had the same solutions, and because of that reason, it was considered to be enough to investigate appropriate solutions for only one or two events for every hazard.

The criteria´s that was chosen, *Risk reduction, Costumer trust for the solutions, Availability and Cost estimation,* did in some way affect the project in the mean that several solutions could not be possible to implement even though the solution had a high risk reduction. For example, a combination with sand filter and SODIS would improve the water quality significant. It was noticed that, for the solution to be handled correctly and be exposed in the sun for two days, the solution needed to be structured at the school. After conversation with Charles Bahati, where he shared earlier experience of that kind of projects it was clear that it would not work because of the maintenance of SODIS. Even though some solutions had a high risk reduction, the needing of maintenance result in low grading for costumer trust.

For the new tank it will be important that the catchment area will be big enough to collect as much water as possible. It can seem to be dissociating to build a new tank when it is two existing tank that in the moment not fills up during some rain falls. But though Mavuno not was interested in implement something on the existing tanks, because of the risk that they get the blame for something that breaks, it was not possible. The same was for repairing the tanks, install a first flush system and install a pump and a tap. Therefor these solutions only were implemented on the new tank. One more consideration for the pump was that the few pumps that existed in Karagwe was expensive and ordered from a town 12 hours away by car, with no one knowing how it worked in the area.

When calculation of the collected water from the catchment area was made, it was important to know that the rain data was based only on three years (2015-2017). This means that the rain depth is not reprehensive for every year to come, and because of the climate change the rain season differ even more. It is also important to consider the reality where it changes how much water that will be collected, according to calculations the collected water is only 85% of the rain depth. This can change depending of roof quality, the depth of the rain, wind and other parameters. Therefore, the result could be misleading and differ from the reality.

5.3.1 Discussion of the implemented technical solution

An already existing and tested manual of tank construction from Mavuno was a better alternative, than design a new tank with materials and technics that probably doesn’t exist in the area and would probably make the construction go slower. Mavunos expertise is an obvious advantage and moreover, the constructors and workers already have the knowledge in choosing the right local material, designing and building a rain water tank that fit the area and the culture in the best way.

When deciding which kind of rain water tank to build at Rukole Primary School an underground tank first was considered. Because of regulations from Mavuno, the only alternative for a Primary school was to build an over ground tank due to safety. Even though, an underground tank was easier and much cheaper to construct compared to an over ground tank it was not possible. This was somehow problematic for the project because it affected the finance and therefore also the time schedule for the construction.

When making a new construction it is important for the owners to feel responsible for their property. One way of facilitate the transmission of the tank, was to include the school in the planning and construction to provide with local material as well as labour. Sometimes, it can be hard for schools to provide with local material as fast as needed, because of their limited economy and possibilities of transportation. This means that for some schools it can take about two years to collect local material. This was a big problem in the project, because of the tight time table. Discussions and negotiations between the project members, Mavuno and the village lead to a compromise that they should finance the local material they can afford in this short time, and the rest will be payed from donors. In the end the compromise was not that big and the school did almost contribute with all the local material that Mavuno requested.

5.4 Education

It is a challenge to educate students about hygiene and sanitation when Rukole Primary School’s standard is low and they lack water every day. Because of earlier discussions regarding the struggle in teaching about good hygiene without enough water on site about the lead to an education plan that was formed with a long-term perspective.

Even if the new tank would work properly with treatment steps, probably the students still will be sick if they don’t have the right knowledge about hygiene and sanitation. In addition, it is hard to say if the students get sick from the water at the school or if it is from their homes. Therefore, education was necessary to spread the knowledge to the students’ homes and families as well. Furthermore, it is important that the school gets educated in different treatment steps. One solution that were presented but not implemented in the report was boiling the water. The reason for that was that the education needed to take place first to be sure that the respect for the solution will be enough to ensure that the solution will be maintained. Because of the limited time schedule, it was not possible to implement the two solutions *boil* and *SODIS*, therefore, only education about the solutions were implemented.

Another difficulty in the project was the fact that it is hard to make sure or to guarantee that the education continues after the project group left. On the other hand, while the project group daily worked at the school, the feeling was that the teachers were convinced about the education material and often showed their joy about learning it to the students. This speaks for the fact that the education will continue. In the purpose to try to document both the education and construction, members from Engineers Without Borders will join in some classes about water, hygiene and sanitation later on and supply with documents of the ongoing process. In addition, they will try to help if there are any problems or struggles regarding the education the project group came up with. Furthermore, it is also hard to measure how profitable the education will be and how much it improves the knowledge and motivation both for the students and their relatives. The project tried to improve it through follow-up and relevant information on the diploma. However, the project group got a really good feeling about the students’ motivation and interest in the subject. In the classes the students were excited and proud because of the homework.

5.5 Water quality

The quality of the water at Rukole Primary School is bad compared to both Swedish, Tanzanian and general guidelines for drinking water. Even though Tank 1 had slightly better results than Tank 2 the numbers of bacteria in the samples are extremely high. In the case with Tank 2 the result was as high as the analyse method could measure. This means that the amount of bacteria could easily be higher than that, only it’s not measurable. One great discussion during this field study was if the quality of the water even should be included since it showed that the quantity of water at the school were so much worse than expected. However, the quality is important, and it will affect the health of the students as well as their study results. Teachers say that the results are suffering because they can’t keep up the concentration due to water scarcity and gets sick often. Therefore, the quality is still included because it is something that’s needs to be improved in the long run to be able to ensure good health among the students. In Sweden water containing only one bacteria wouldn’t be distributed at all because of health concerns but at the school they drink water with so much more. It is hard to believe that there are “only” 400 student every day that are home, with this quality in Sweden for example, almost everybody would be sick. There is a difference in how people react to bacteria in the water and somehow these people are more resistant to it because they are being exposed to it daily. However, there is no reason for not trying to improve the situation since safe drinking water should be provided to all.

6. Conclusion

- The most urgent risk for the quality was *Buckets for collecting water places in feces reaches the water,* which also was confirmed by the result of water quality testing in the two tanks – Tank 2, where buckets were used had worse quality thank Tank 1. *Feces from animals on the catchment area get in contact with the water that reaches the tank*, *Hands that contaminate the water and the buckets* and *The amount of students is to high compared to the size of the tanks* were three other hazardous events that were urgent risks for the water situation.

- Solutions that were presented as appropriate but not implemented were *boil, first flush, clean the catchment area, install a pump and tap, wash hands, repair the tanks and lead more pipes from more roofs.*

- *Build a new tank,* was the technical solution that was implemented at the school. It was necessary because the school did not have enough water, and it was not possible to treat water that does not exist. An over ground 90m^3 tank, with a total catchment area of 875 m^2 will provide the school with totally about 1100m^3 collected water for one year. All the three tanks included, will provide with enough water regarding guidelines from Food and Nutrition Board (2004) and WHO (n.d).

- Because of the problems with hygiene and sanitation as well as the knowledge and respect for clean and safe water at the school, education about water, sanitation and hygiene was necessary before implementing any solution to improve the quality.

- In order to feel ownership and take responsibility of the education the teachers was involved during the planning process, and it was also them who held the education during the field study. For the new tank the school provided with local material and labour to the construction of the new tank.

6.1 Future projects

- Investigate hazards that appear in the water due to viruses, parasites and chemicals.

- Further WASH-education in the area including how to perform different household treatment methods to reduce waterborne diseases.

- Implement and improve biogas as energy source that can be used for schools to treat water, for example by boiling.

- Design a pump for existing tanks in the area with and a manual for construction and maintenance.

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Appendix 1

Table a Hazardous event regarding quality for zone A. Catchment area.

Zone	Hazardous event	Description of hazardous event	Probability, P	Conseq. Quality, C1	Risk 1
A.	A1	Feces from animals on the catchment areaget in contact with the water that reaches the tank	8	81	648
	A2	Contaminated feet and shoes on the roof and contaminate the water	2	81	162
	A3	Dead animal on the roof and get in contact with water	2	3	6
	A4	Dust and particals falls on the roof get in contact with the water and reaches the tank	8	3	24
	A5	Dust and particals in the pipes get in contact with the water in the tank	8	3	24

Table b Hazardous event regarding quality for zone B. Water storage

Zone	Hazardous event	Description of hazardous event	Probability, P	Conseq. Quality, C1	Risk 1
B.	B1	Feces from animals inside the tank through the hatch	8	81	648
	B2	Insects bring feaces to the tank	16	3	48
	B3	Buckets for collecting water places in feaces reaches the water	16	81	1296
	B4	Objects falls down trought the hatch	4	9	36
	B5	Contaminated hands in the tank	4	81	324
	B6	Children are playing on the roofs of the tanks	8	9	72
	B7	Feces from animals leaks in trough the roof of the tank	8	81	648
	B8	The area get floded and water leaks inside the tanks	2	81	162

Table c Hazardous event regarding quality for zone C. Distribution of water

Zone	Hazardous event	Description of hazardous event	Probability, P	Conseq. Quality, C1	Risk 1
C.	C1	Hands that contaminate the water and the buckets	16	27	432
	C2	Insect bring feaces to the buckets	8	9	72
	C3	Animal in contact with feaces drinks from buckets	4	3	12

Table d Hazardous event regarding quantity for zone A. Catchment area, B. Water storage and C. Distribution of water

Zone	Hazardous event	Description of hazardous event	Probability, P	Conseq. Cuantity, C2	Risk 2
A.	A8	Roof breaks and do not work as water catcher	1	81	81
	A9	The pipes breaks during rainfall	1	81	81
	A10	The catchment area is not enough during rain falls	4	27	108
B.	B9	The tank leaks	4	81	324
	B10	The amount of students is to high compared to the size of the tanks	16	81	1296
C.	C5	Not enough buckets for distribution	16	3	48

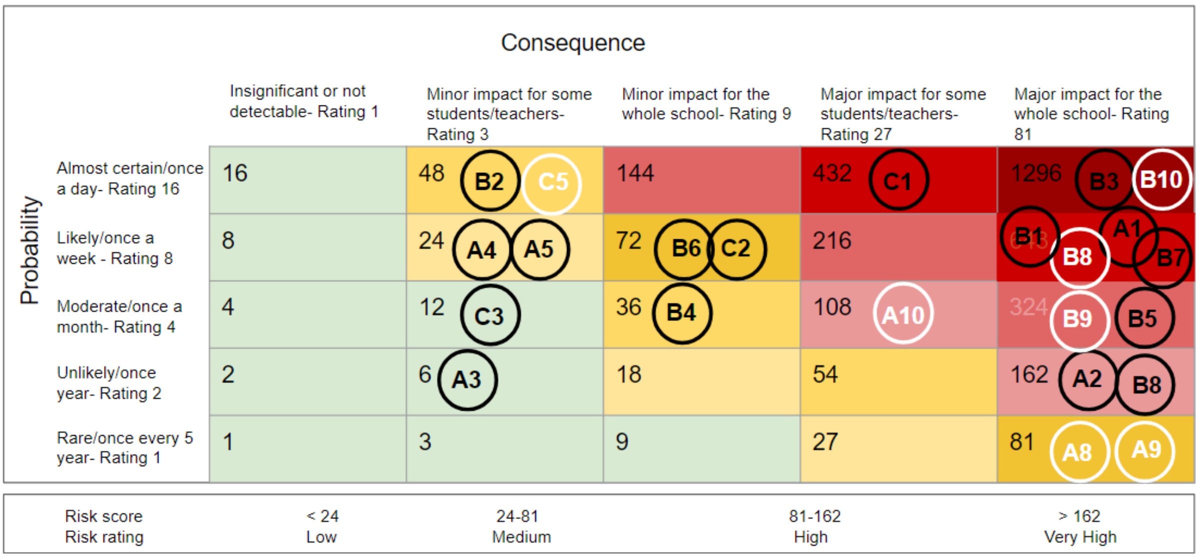

Figure a The final risk matrix with every hazardous event

Equation a Total volume of water distributed for one year

$$\left(1500 * 0{,}6\ \frac{l}{day} + 18 * 10\ l/day\right) * 260 = 280\ m3/år$$

Equation b Total volume of water for one year

$$\left(1500 * 2{,}5\ \frac{l}{day} + 18 * 20\ l/day\right) * 260 = 1000\ m3/år$$

Appendix 2

Table e, Hazardous event A1

Hazardous Event	Solution nr.	P	P'	C1	C1'	R1	R1'	ΔR1	n (ΔR)
A1.	1	8	8	81	9	648	72	576	0,90
	1;5	8	8	81	3	648	24	624	0,98
	1;5;4	8	8	81	1	648	8	640	1,00
	2	8	8	81	3	648	24	624	0,98
	2;1	8	8	81	1	648	8	640	1,00
	2;4	8	8	81	1	648	8	640	1,00
	2;1;4	8	8	81	1	648	8	640	1,00
	3	8	8	81	3	648	24	624	0,98
	3;1	8	8	81	1	648	8	640	1,00
	3;4	8	8	81	1	648	8	640	1,00
	3;1;4	8	8	81	1	648	8	640	1,00
	4	8	8	81	9	648	72	576	0,90
	6	8	8	81	1	648	8	640	1,00
	7;6	8	8	81	1	648	8	640	1,00
	7;1;5	8	8	81	3	648	24	624	0,98
	8	8	4	81	81	648	324	324	0,51
	16	8	4	81	81	648	324	324	0,51
	8;16	8	1	81	81	648	81	567	0,89

Solution nr.	Avalibility	n (Av.)	Cost Estimation [USD]	n (Cost.)	Costumer Trust	n (Co. T)	TOTAL
1	0,8	1	62	0,78	2	0,4	0,77
1;5	0,8	1	70	0,75	2	0,4	0,78
1;5;4	0,4	0,5	99	0,65	2	0,4	0,64
2	0,6	0,75	52	0,82	1	0,2	0,69
2;1	0,6	0,75	114	0,60	1	0,2	0,64
2;4	0,4	0,5	81	0,71	1	0,2	0,60
2;1;4	0,4	0,5	143	0,50	1	0,2	0,55
3	0,4	0,5	193	0,32	3	0,6	0,60
3;1	0,4	0,5	255	0,10	2	0,4	0,50
3;4	0,4	0,5	222	0,22	2	0,4	0,53
3;1;4	0,4	0,5	284	0,00	2	0,4	0,48
4	0,4	0,5	29	0,90	2	0,4	0,67
6	0,8	1	45	0,84	3,5	0,7	0,89
7;6	0,8	1	45	0,84	5	1	0,96
7;1;5	0,8	1	70	0,75	4	0,8	0,88
8	0,6	0,75	100	0,65	3	0,6	0,63
16	0,8	1	20	0,93	3	0,6	0,76
8;16	0,6	0,75	120	0,58	3	0,6	0,70

Table f, Hazardous event B3

Hazardous Event	Solution nr.	P	P'	C1	C1'	R1	R1'	ΔR1	n (ΔR)
B3	1	16	16	81	9	1296	144	1152	0,89
	1;5	16	16	81	3	1296	48	1248	0,96
	1;5;4	16	16	81	1	1296	16	1280	0,99
	2	16	16	81	3	1296	48	1248	0,96
	2;1	16	16	81	1	1296	16	1280	0,99
	2;4	16	16	81	1	1296	16	1280	0,99
	2;1;4	16	16	81	1	1296	16	1280	0,99
	3	16	16	81	3	1296	48	1248	0,96
	3;1	16	16	81	1	1296	16	1280	0,99
	3;4	16	16	81	1	1296	16	1280	0,99
	3;1;4	16	16	81	1	1296	16	1280	0,99
	4	16	16	81	3	1296	48	1248	0,96
	6	16	16	81	1	1296	16	1280	0,99
	7;17	16	1	81	81	1296	81	1215	0,94
	7;6	16	16	81	1	1296	16	1280	0,99
	7;1;5	16	4	81	3	1296	12	1284	0,99
	6;9	16	1	81	1	1296	1	1295	1,00
	17	16	1	81	81	1296	81	1215	0,94
	9	16	1	81	81	1296	81	1215	0,94

Solution nr.	Avalibility	n (Av.)	Cost Estimation [USD]	n (Cost.)	Costumer Trust	n (Co. T)	TOTAL
1	0,8	0,8	62	0,82	2	0,4	0,73
1;5	0,8	0,8	70	0,80	2	0,4	0,74
1;5;4	0,4	0,4	99	0,71	2	0,4	0,63
2	0,6	0,6	52	0,85	1	0,2	0,65
2;1	0,6	0,6	114	0,67	1	0,2	0,61
2;4	0,4	0,4	81	0,77	1	0,2	0,59
2;1;4	0,4	0,4	143	0,59	1	0,2	0,54
3	0,4	0,4	193	0,44	3	0,6	0,60
3;1	0,4	0,4	255	0,26	2	0,4	0,51
3;4	0,4	0,4	222	0,36	2	0,4	0,54
3;1;4	0,4	0,4	284	0,18	2	0,4	0,49
4	0,4	0,4	29	0,92	2	0,4	0,67
6	0,8	0,8	45	0,87	3,5	0,7	0,84
7;17	0,8	0,8	20	0,94	5	1	0,92
7;6	0,8	0,8	45	0,87	5	1	0,91
7;1;5	0,8	0,8	70	0,80	3	0,6	0,80
6;9	0,2	0,2	345	0,00	3	0,6	0,45
17	0,8	0,8	20	0,94	2	0,4	0,77
9	0,3	0,3	300	0,13	3	0,6	0,49

Table g, Hazardous event B7

Hazardous Event	Solution nr.	P	P'	C1	C1'	R1	R1'	ΔR1	n (ΔR)
B7	1	8	8	81	9	648	72	576	0,90
	1;5	8	8	81	3	648	24	624	0,98
	1;5;4	8	8	81	1	648	8	640	1,00
	2	8	8	81	3	648	24	624	0,98
	2;1	8	8	81	1	648	8	640	1,00
	2;4	8	8	81	1	648	8	640	1,00
	2;1;4	8	8	81	1	648	8	640	1,00
	3	8	8	81	3	648	24	624	0,98
	3;1	8	8	81	1	648	8	640	1,00
	3;4	8	8	81	1	648	8	640	1,00
	3;1;4	8	8	81	1	648	8	640	1,00
	4	8	8	81	3	648	24	624	0,98
	6	8	8	81	1	648	8	640	1,00
	7;6	8	8	81	1	648	8	640	1,00
	7;1;5	8	8	81	3	648	24	624	0,98
	11	8	1	81	81	648	81	567	0,89

Solution nr.	Avalibility	n (Av.)	Cost Estimation [USD]	n (Cost.)	Costumer Trust	n (Co. T)	TOTAL
1	0,8	1	62	0,96	2	0,4	0,81
1;5	0,8	1	70	0,95	2	0,4	0,83
1;5;4	0,4	0,5	99	0,93	2	0,4	0,71
2	0,6	0,75	52	0,97	1	0,2	0,72
2;1	0,6	0,75	114	0,92	1	0,2	0,72
2;4	0,4	0,5	81	0,95	1	0,2	0,66
2;1;4	0,4	0,5	143	0,90	1	0,2	0,65
3	0,4	0,5	193	0,87	3	0,6	0,74
3;1	0,4	0,5	255	0,83	2	0,4	0,68
3;4	0,4	0,5	222	0,85	2	0,4	0,69
3;1;4	0,4	0,5	284	0,81	2	0,4	0,68
4	0,4	0,5	29	0,98	2	0,4	0,71
6	0,8	1	45	0,97	3,5	0,7	0,92
7;6	0,8	1	45	0,97	5	1,0	0,99
7;1;5	0,8	1	70	0,95	4	0,8	0,93
11	0,6	0,75	1500	0,00	2	0,4	0,51

Table h, Hazardous event C1

Hazardous Event	Solution nr.	P	P'	C1	C1'	R1	R1'	ΔR1	n (ΔR)
C1	1	16	16	27	9	432	144	288	0,69
	1;5	16	16	27	3	432	48	384	0,92
	1;5;4	16	16	27	1	432	16	416	1,00
	2	16	16	27	3	432	48	384	0,92
	2;1	16	16	27	1	432	16	416	1,00
	2;4	16	16	27	1	432	16	416	1,00
	2;1;4	16	16	27	1	432	16	416	1,00
	3	16	16	27	3	432	48	384	0,92
	3;1	16	16	27	1	432	16	416	1,00
	3;4	16	16	27	1	432	16	416	1,00
	3;1;4	16	16	27	1	432	16	416	1,00
	4	16	16	27	3	432	48	384	0,92
	6	16	16	27	1	432	16	416	1,00
	7;17	16	2	27	27	432	54	378	0,91
	7;6	16	16	27	1	432	16	416	1,00
	7;1;5	16	16	27	3	432	48	384	0,92
	12	16	2	27	27	432	54	378	0,91
	17	16	2	27	27	432	54	378	0,91

Solution nr.	Avalibility	n (Av.)	Cost Estimation [USD]	n (Cost.)	Costumer Trust	n (Co. T)	TOTAL
1	0,8	0,8	62	0,78	2	0,4	0,67
1;5	0,8	0,8	70	0,75	2	0,4	0,72
1;5;4	0,4	0,4	99	0,65	2	0,4	0,61
2	0,6	0,6	52	0,82	1	0,2	0,63
2;1	0,6	0,6	114	0,60	1	0,2	0,60
2;4	0,4	0,4	81	0,71	1	0,2	0,58
2;1;4	0,4	0,4	143	0,50	1	0,2	0,52
3	0,4	0,4	193	0,32	3	0,6	0,56
3;1	0,4	0,4	255	0,10	2	0,4	0,48
3;4	0,4	0,4	222	0,22	2	0,4	0,50
3;1;4	0,4	0,4	284	0,00	2	0,4	0,45
4	0,4	0,4	29	0,90	2	0,4	0,66
6	0,8	0,8	45	0,84	3,5	0,7	0,84
7;17	1	1	20	0,93	5	1,0	0,96
7;6	0,8	0,8	45	0,84	5	1,0	0,91
7;1;5	0,8	0,8	70	0,75	4	0,8	0,82
12	0,6	0,6	28	0,90	4	0,8	0,80
17	0,8	0,8	10	0,96	3	0,6	0,82

Table i Hazardous event A9, B8, B10, A10

Hazardous Event	Solution nr.	P	P'	C1	C1'	R1	R1'	ΔR1	n (ΔR)
A9	14	2	1	81	81	162	81	81	0,6
	13	2	1	81	27	162	27	135	1,0
	13;14	2	1	81	27	162	27	135	1,0
B8	10	4	1	81	27	324	27	297	1,0
	11	4	2	81	81	324	162	162	0,5
	10;11	4	1	81	27	324	27	297	1,0
B10	10	4	1	81	81	324	81	243	1,0
A10	13	4	2	81	81	324	162	162	1,0

Solution nr.	Avalibility	n (Av.)	Cost Estimation [USD]	n (Cost.)	Costumer Trust	n (Co. T)	TOTAL
14	0,5	1,0	3000	0,06	2	0,7	0,65
13	0,5	1,0	200	0,94	3	1,0	0,99
13;14	0,5	1,0	3200	0,00	2	0,7	0,77
10	0,3	0,5	10000	0,13	5	1,0	0,81
11	0,6	1,0	1500	0,87	3	0,6	0,69
10;11	0,6	1,0	11500	0,00	3	0,6	0,74
10	0,3	1,0	10000	0	5	1,0	0,90
13	0,5	1,0	200	0	3	1,0	0,90

Appendix 3

Table j Collected water during one year from the two existing tanks and from the new tank.

	1 år			
	Area Tak [m2]	**Regnfall 1 år [m]**	**Vatten som samlas upp**	**Volym vatten under 1 år [m3]**
Tank 2	175	0,902	0,85	134,20225
Tank 1	350	0,902	0,85	268,4045
Ny tank	875	0,902	0,85	671,01125
Totalt	1400	0,902	0,85	1073,618

Table k If catchment area would be 175m^2 bigger the volume of collected water would be 536 m^3.

1 år			
Area Tak [m2]	**Regnfall 1 år [m]**	**Vatten som saml**	**Volym vatten under 1 år [m3]**
350	0,902	0,85	268,4045
350	0,902	0,85	268,4045
700	0,902	0,85	536,809

Table l The rain data is during one year. The data is from 2015-2017 and is retrieved from world weather online (2017).

Månad	Regn/dag [mm]
Januari	34
Februari	118
Mars	66
April	151
Maj	67
Juni	24
Juli	13
Augusti	36
September	44
oktober	88
november	183
december	78
Totalt [mm/år]	902

Table m Collected water during January

	January			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,034	0,85	5
Tank 1	350	0,034	0,85	10
Total				15

Table n Collected water during every month for the first rain season, Feb-May

	February			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,118	0,85	18
Tank 1	350	0,118	0,85	35
Total				53
	March			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,066	0,85	10
Tank 1	350	0,066	0,85	20
Total				30
	April			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,151	0,85	22
Tank 1	350	0,151	0,85	45
Total				67
	May			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,067	0,85	10
Tank 1	350	0,067	0,85	20
Total				30

Table o The total collected water during Feb-May

Feb - May	Total Volym [m3]
Tank 2	60
Tank 1	120
Total	179

Table p Collected water during every month for the dry season, Jun-May

	June			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,024	0,85	4
Tank 1	350	0,024	0,85	7
Total				11
	July			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,013	0,85	2
Tank 1	350	0,013	0,85	4
Total				6
	August			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,036	0,85	5
Tank 1	350	0,036	0,85	11
Total				
	September			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,044	0,85	7
Tank 1	350	0,044	0,85	13
Total				20

Table q The total collected water during Jun-Sep

Jun-Sep	Total Volym [m3]
Tank 2	17
Tank 1	35
Total	52

Table r Collected water during every month for the first rain season, Oct-Dec

	October			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,088	0,85	13
Tank 1	350	0,088	0,85	26
Total				39
	November			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,183	0,85	27
Tank 1	350	0,183	0,85	54
Total				81
	December			
	Area Tak [m2]	Regnfall 1 mån [m]	vatten som samlas upp	Volym vatten under 1 mån [m3]
Tank 2	175	0,078	0,85	12
Tank 1	350	0,078	0,85	23
Total				35

Table s The total collected water during Oct-Dec

Oct- Dec	Total volym [m3]
Tank 2	52
Tank 1	104
Total	156

Appendix 4

This appendix contains education material for Rukole Primary School: a workshop designed for the teachers and two lessons designed for the student. The language is on a basic level, in the aim to make it easier for the involved to understand. The knowledge in English varies a lot and therefore this material was translated into Swahili and used in Swahili. The workshop was held in Swahili with a translator.

Workshop for teachers

Project team: Thank you for having us today. So kind of you that you want to discuss some things with us today about water and hygiene.

We know that rainwater is clean when it comes from the sky but still the water here is really dirty. If a new tank will be built, we want to discuss with you how this dirt can be prevented in the best way.

Therefore, we want to divide you in to four groups to discuss:

- Where the dirt comes from
- Hygiene, and how it can affect the water
- What you say to the students today about hygiene and how it can be better
- Which kind of solutions that you think could prevent the contamination
- The new tank

We want you to discuss in the groups and write down your thoughts on the paper. After you have written your thoughts we discuss in the big group. *Divide the teachers into groups of 4-5 and hand out papers with the questions.*

Read the questions out load in front of everyone and let the teachers discuss in the small groups and write down their answers.

PAGE 1:

- What you think the dirt come from in the water?
- In the water that we have tested there is a lot of bacteria that are called E.coli and Coliform. Do you know what that bacteria come from and what they do if you drink them?

Summarize and talk in big group what they said.

The bacteria come from feces. The most urgent problem with the water quality is feces from animals and humans. (If they do not mention feces at all we let them discuss again where the dirt come from when they know that feces are the most urgent problem for the quality)

- Imagine a day, what do you think reaches the water during a day? How can poop reach the water during a day? *Let the teachers discuss again.*

Summarize and talk in big group what they said.
Example where the feces reach the water: Flies, birds, animals, dirty hands, buckets that has been placed in feces.

PAGE 2:

- How do you think hygiene affect the water quality?
- What do you say to the students about hygiene? How often do you talk about it?
- How do you think that education about hygiene can be good for the water quality?

Summarize the good things they have talked about.

We were thinking that maybe posters with information about hand wash could be a good idea, and also that the students get homework about hygiene. Example of homework they will tell their family and then talk about it in school.

- It is important to wash your hands after toilette, and before eating and drinking. This is because of the bacteria from feces (poop) from humans and animals that makes you sick.
- Clean and scrub your hands properly. Use soap if you have. If you don't have water, you can wash your hands with sand (friction). Show how.
- You can collect wood and boil the water to kill the dangerous bacterias that can give you typhoid and cholera.
- You can put a clean bottle filled with water outside in the sun for 2 days and then the water is clean.
- That it is important to keep the water in safe storage because otherwise the water gets dirty again. Example of safe storage: clean closed bottle, bucket or container.

What do you think about the homework? Is it good ideas? Any input?

Summarize the good things they have talked about.

PAGE 3:
- Which kind of solutions do you think can prevent dirt to reach the drinking water in a new tank?

Summarise what they have said that is good. Present examples if they don't mention.

- Wash hand with clean sand
- Wash hand with soap and water
- New buckets with lid/cover and tap
- Cleaning the buckets with bleach every week
- Education about hygiene and sanitation

Thank you so much for attending and helping us with this arrangement of the education. We will after all this input together with two of you, Josef and Deocles form the education material for the students.

Lesson for students

Experiment with pH. (show what happens when you put lemon or baking powder in the different transparent buckets while adding the indicator BTB)

Teacher in front of the whole class:
Water is alive and changes all the time. Bacteria live in the water and can make you sick. In your tank it happens all the time, the water changes. Because of that you don't have any roof on one of your tanks poops from animals easily can come inside. The dangerous bacteria from the poop can after that grow in the tank. Poop from animals and humans is very dangerous to have in the water.

Can you image that it is like this? If you have a glass of water with bird-poop, would you drink it? Probably not. But it is exactly the same with the water in the tank.

Show the students a water quality test of e-coli and describe what it says and the scale.
Yellow – very much poop
Transparent – clean

Bacteria from poop can make you really sick. You can get diarrhoea, puke, get stomach pain and even die. Can you understand that it is like this? Any Questions? What can you do? You can kill this dangerous bacteria. How? Ideas? *Teachers write on the black board.*

- Boil the water. What happens? All the bacteria die because of the temperature.
- Put water in bottles and in the sun for two days. What happens? All the bacteria dies of the sunlight.
- Pour the water through fabric. What happens? The water gets less dirty. After pouring you can either boil or put in the sun.
- Store the water in a safe and closed bucket to keep it clean. What happens? No bacteria can come inside.

But the most important to remember is: Hygiene, and how it affect the water.
You remember that most of the dangerous bacteria come from poop. When you have been on the toilet there will be poop on your hands. This can easily affect and get in contact with your drinking water, water equipment, food or direct to your mouth!

How can you avoid this? Clean your hands! If you have soap – use it! Try to wash all over the hands and scrub your hand to each other so the dirt comes off. Do this ALWAYS after toilet, and ALWAYS before eating and drinking. *Let the students show each other how to clean their hands in a proper way. Let them play theatre in front of the class if they want.*

We will give you a homework for next week, please write this down so you will remember.
Teacher write on the black board and read it out loud.

- Boil the water to kill all the dangerous bacteria that makes you sick
- Put water in bottles in the sun for 2 days → all the bacteria die
- ALWAYS wash your hands after toilet and before eating and drinking

The homework is that you go home to your friends and family and tell them what you learned here today and try to practice these different treatments step at your homes. We will meet in a week and have a Follow up-lesson, there you will get the chance to discuss the homework and how it went and also share the experiences with each other. In the end of next lesson, you will get a Diploma.

Thank you so much that you listened and that you wanted to know more about the importance of water, hygiene and sanitation with us today!

Follow up-lesson for students

Teacher speaks in front of the class.

- What do you remember from our last lesson about water, hygiene and sanitation?
- Do you remember was the homework was?

Now we want to divide you into small groups of 5-6 persons and you will discuss with your classmates about the following questions: *The teacher write the questions on the black board.*

- How did it go when you tried boiling the water and putted the bottles in the sun? How did you do?
- How did you show your family how to wash your hands?
- Did your family now about that you can clean water this way you have been learned? What did they say about it?
- Was the homework hard? Did you like it?

The teachers gather the students after 10-15 min.

Teacher ask in front of the whole class:
- Will you continue use this knowledge? How? Do you have examples?

Every group can say one thing out load in front of the class.

The things we hope that you have learned from this lessons:

- Boil the water before drinking it to get it clean
- Put bottles in the sun for 2 days to make it cleaner
- Pour water through fabric before boiling or putting in the sun
- After cleaning the water, put it in a safe and closed storage to keep it clean
- Always wash your hands after toilet and always before eating and drinking

This information is also on the backside of the DIPLOMA you will get now.
Thank you so much for learning about water, hygiene and sanitation.

Organize to hand out the diplomas to the students.