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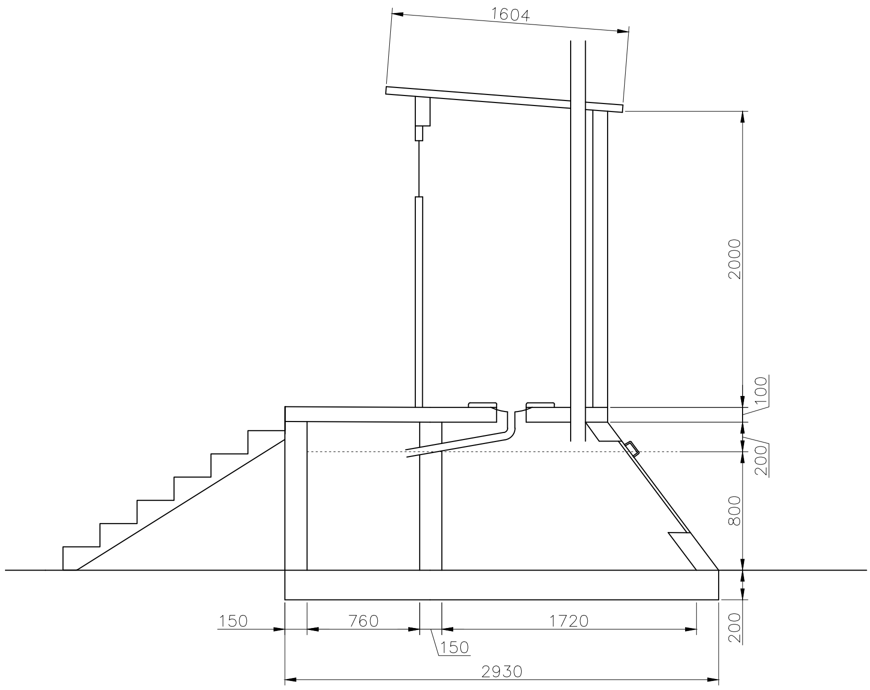

One solution to the sanitary situation in Bulyaheke, Tanzania

Evaluation and design of a double pit urine diverting dry toilet

Master's thesis in the Master's Programme Infrastructure and Environmental Engineering

EBBA ELIASSON

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
DIVISION OF WATER ENVIRONMENT TECHNOLOGY

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MASTER'S THESIS ACEX30

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Examensarbete ACEX30
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Cover:
The cover shows a drawing of the designed toilet solution from the side, which also is shown as Figure 11 in the report.

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Abstract

Despite the fact that the international community have agreed that all people should have access to safe sanitation and hygiene by the year 2030 through the Sustainable Development Goals, that is far from the situation today. One country that is particularly exposed is Tanzania, where 62 % of the schools do not have enough toilets for the students and less than 10 % of the schools have handwashing facilities. In the rural village Bulyaheke there are two adjacent schools which together have over 4100 students but only 6 toilets. The toilets barely work and there are no handwashing facilities. This study aims to design a solution that can improve the sanitary situation and reduce the risk of sanitary diseases at the two schools, and hopefully for other parts of the area in the long run. To achieve this goal, two potential solutions have been evaluated and compared based on information from previous studies in the area. One solution is called Fossa Alterna and is a type of urine diverting dry toilet with double pits. The toilet decompose waste through composting process and the finished compost can be used as fertiliser after storage for six months. The second solution is a biodigester with biogas extraction. In that case the waste is digested under anaerobic conditions at the same time as methanogenic bacteria produces biogas that can be used as an energy source. Based on the local prerequisites, the Fossa Alterna is recommended as a solution as it is a technically simpler solution that does not require any water to function and is easy to maintain. This solution is then designed with drawings, material and construction suggestions and a cost estimation. Furthermore, it is recommended to collect rainwater from the roof of the schools to use for handwashing and other hygiene purposes.

Key words: Ecological Sanitation, Rainwater Harvesting (RWH), Sanitation facilities, Toilet facilities, Urine Diverting Dry Toilet (UDDT), SWASH

En lösning till den sanitära situationen i Bulyaheke, Tanzania

Utvärdering och design av en urinseparerande torrtoalett med dubbla kammare

Examensarbete inom mastersprogrammet Infrastruktur och Miljöteknik

EBBA ELIASSON
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Avdelningen för Vatten Miljö Teknik

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Sammanfattning

Trots att världens länder har enats om att alla människors ska ha tillgång till säker sanitet och hygien till år 2030 genom de 17 globala målen, är vi långt därifrån idag. Ett land som är särskilt utsatt är Tanzania där 62 % av skolorna saknar tillräckligt många toaletter för eleverna och mindre än 10 % av skolorna har möjligheter att tvätta händerna. I byn Bulyaheke finns två angränsande skolor som tillsammans har över 4100 elever men endast 6 toaletter. Toaletterna fungerar knappt och möjligheter att tvätta händerna i de två skolorna saknas helt. Den här studien syftar till att designa en lösning som kan förbättra den sanitära situationen och minska risken för sanitära sjukdomar på de två skolorna, och förhoppningsvis för fler delar av området på längre sikt. För att uppnå detta mål har två potentiella lösningar utvärderats och jämförts utifrån information från tidigare studier i området. Den ena lösningen kallas Fossa Alterna och är en typ av urinseparerande torrtoalett med dubbla kammare. Toaletten bryter ned mänskligt avfall genom kompostering och den färdiga komposten kan användas som gödsel efter lagring under sex månader. Den andra lösningen är en bio-nedbrytare med biogas-utvinning. Där bryts mänskligt avfall ner under anaeroba förhållanden samtidigt som bakterier producerar biogas som kan användas som energikälla. Utifrån de lokala förutsättningarna rekommenderas Fossa Alterna som lösning då den är en tekniskt enklare lösning som inte kräver något vatten för att fungera och är enkel att underhålla. Denna lösning är sedan designad med ritningar, materialförslag och kostnadsuppskattning. Vidare rekommenderas att samla regnvatten från skolornas tak för att använda till handtvätt och andra hygiensyften.

Nyckelord: Ekologisk sanitet, skörd av regnvatten (RWH), sanitetsfaciliteter, toalett, urinseparerande torrtoalett (UDDT), SWASH

Contents

Preface

This project is done in collaboration with Engineers Without Borders Sweden (EWB-SWE) who initiated the project and have assisted with background information and support on technological and social aspects. Special thanks to the project coordinator Elin Fransson and project manager Lauren Meredith who both have assisted a lot throughout the project. Thank you to Debora Falk from EWB-SWE who have contributed with important aspects from personal experiences of fieldwork in developing countries. Furthermore, without the previous studies by Elin Fransson & Anna Werner on SODIS treatment and by Elin Augustsson & Angelica Nylund on the sanitary situation in Bulyaheke, there would be no information about local conditions and prerequisites to base this thesis on. Finally a thank you to my supervisor Oskar Modin and examiner Britt-Marie Wilén at Chalmers University of Technology.

Göteborg January 2021
Ebba Eliasson

Abbreviations

EcoSan - Ecological Sanitation
EWB-SWE - Engineers Without Borders Sweden
FUO - Fishers Union Organisation
HDI - Human Development Index
MDGs - Millennium Development Goals
RWH - Rainwater Harvesting
SDGs - Sustainable Development Goals
SODIS - Solar water disinfection
SWASH - School Water, Sanitation and Hygiene
TS - Total Solids
UDDT - Urine Diverting Dry Toilet
UN - United Nations
UNHCR - United Nations High Commissioner for Refugees
UNICEF - United Nations Children's Fund
VIP Latrine - Ventilated Improved Pit Latrine
VS - Volatile Solids
WASH - Water, Sanitation and Hygiene
WHO - World Health Organisation

1 Introduction

In Sweden today, clean water and safe sanitation is taken for granted. Human health, child development, the environment and economic and social growth are all affected by the sanitation situation. Most of the Swedish population have access to safe drinking water through the faucets in our homes, unlimited amounts and all the time. That is not the situation in the rest of the world. In year 2017 only 45 % of the global population had access to safely managed sanitation (UNICEF & WHO, 2020), leaving 2 billion people without access to even basic sanitation, including 673 million people with no sanitation services at all, with open defecation as only alternative. Nevertheless, safe sanitation and clean water is a human right since 2010 (United Nations General Assembly, 2010) and the United Nations (UN) Member States have agreed to "achieve access to adequate and equitable sanitation and hygiene for all and end open defecation" (United Nations, 2020a, p. 1) by year 2030 through the Sustainable Development Goals (SDGs). However, the sanitation development is going slow and need to move four times faster to reach these goals in time.

One of the countries where a lot of work needs to be done regarding the sanitation situation is Tanzania in eastern Africa. For example, in year 2020, 52 % of health care facilities in Tanzania had no improved sanitation services or none at all, which was the worst number amongst the 70 countries investigated (UNICEF & WHO, 2020). In 2016, 62 % of the schools in Tanzania lacked sufficient number of toilets for the students and less than 10 % of the schools had handwashing services (Ministry of Education Science and Technology, 2016). The poor sanitation situation is a source of diseases and pollution and the situation in the school also risks affecting school attendance of especially the girls, due to their needs of safe and adequate sanitation and hygiene facilities during menstruation.

The currently ongoing pandemic of Covid-19 has affected the whole world and enhanced the importance of water, sanitation and hygiene (UNICEF & WHO, 2020), but also shown that formidable change and global cooperation is possible.

1.1 Problem formulation

Two recent master thesis studies at Chalmers have been performed in the area of the rural village Bulyaheke in northern Tanzania. The projects were first initiated in 2017 by Engineers Without Borders Sweden (EWB-SWE) together with the local Fishers Union Organization (FUO). EWB-SWE had previously done other projects in the region, indicating poor access to safe drinking water and critical sanitation situations in the fishing villages along the shore of Lake Victoria.

The first thesis study by Fransson and Werner (2019) examined the possibilities of solar water disinfection (SODIS) as household water treatment and concluded that it is a feasible short term solution to reach the SDG of clean water in the area. The second study, by Nylund and Augustsson (2020), investigated the sanitation situation in the area and concluded that the local population often suffers from sanitary related diseases and that the sanitary situation of two adjacent schools in Bulyaheke is deficient. The two schools have no handwashing facilities and only six pit toilets, barely working, for over 4000 students. The study moreover evaluated and compared some different dry toilet solution alternatives. Their recommendation is to build a kind of ecological sanitation (EcoSan) system with dry toilets, called Fossa Alterna, at the schools, together with rainwater harvesting (RWH) for handwashing and other sanitary purposes. The implementation of sanitation facilities at the schools are suggested to work as a pilot project, both in terms of realising if the suggested solution is a feasible alternative, but also to inspire and educate the rest of the population in the area to construct similar facilities. Furthermore, their recommendation is to further explore the possibility of implementing this pilot project at the schools and to evaluate the acceptance, performance and operational design of the suggested solution. This is where this project succeeds, to further evaluate the suggested solution and to finish the design process.

1.2 Aim and objectives

This project aims to get a step closer to improving the sanitary situation for the two schools by recommending and designing a suitable toilet solution. Furthermore, the aim is for the solution to be modular and adaptable for possible later implementation in other parts of Bulyaheke or in other future projects. For this purpose, the two schools will work as a pilot project to conclude feasibility of the solution and inspire further sanitary development in the area.

The recommended toilet solution from the previous study by Augustsson and Nylund (2020) is further investigated and a biodigester solution with biogas production will be investigated as well. The two solutions are then evaluated and compared to see which one is most suitable for the two schools. The most suitable solution is then designed with drawings, cost estimation and material suggestions to be used as basis for funding and implementation.

1.3 Research questions

To reach the aim of this project, the following research questions are considered:

- What kind of toilet solution will be most beneficial and feasible for the situation of the two schools in Bulyaheke?
- How can solution alternatives be compared in a suitable and objective way? What criteria are important to consider?
- What is a suitable design of the found solution? What are the costs and what materials can be used?
- What is the required maintenance for the solution and how can it be secured? Who is responsible?
- What are the risks/limitations of the solution and how can they be reduced/avoided?
- How can the solution work as a pilot project for inspiration and be adapted and implemented in other parts of the area?
- Can the results from the SODIS study be implemented as water treatment for the RWH at the schools?

1.4 Limitations

Due to the present pandemic of Covid-19 it was not possible to do any field trips to Bulyaheke, hence no on-site testing or user surveys were feasible. Instead, data and observations from the two previous studies is the main source of information about the local prerequisites. However, their aim was slightly different than the one of this study, so the focus of the data was not optimised for this project. There was also no answer from the FUO or other local contacts during the extent of this project, maybe also due to Covid-19. The intention of communication with these contacts was to get answer to questions about the local prerequisites or possibly assistance with digital user surveys. Consequently, this study includes several assumptions about prerequisites based on previous similar projects.

Even without the Covid-19 pandemic or communication problems there is neither budget nor equipment to do a hydrogeological investigation or other on-site testing. i.e. what would have been the normal procedure when doing any sanitation project in Sweden. The construction budget for the project is also very limited, since it relies mainly on charity funding the goal is to keep it as small as possible. This together with locally available material, maintenance possibilities, cultural aspects and water scarcity put a lot of constraints on the solution design.

2 Background

2.1 Tanzania and Bulyaheke

Tanzania, officially the United Republic of Tanzania, is a country in eastern Africa with a coastline to the Indian Ocean, see Figure 1 (Central Intelligence Agency, 2020). Tanzania was a part of German East Africa from the late 19th century until the end of World War I when it fell under British rule. In 1964 the two colonial jurisdictions of Tanganyika and the Zanzibar Archipelago merged into the United Republic of Tanzania, after their independence in 1961 and 1963 respectively. Tanzania remains a part of the British Commonwealth. The population of Tanzania is estimated to about 58.5 million people with a high annual growth rate of 3 % and a very young population with almost two thirds of the population being under 25 years of age. Tanzania is a diverse country with about 130 ethnic and religious group and over 100 spoken languages, with Swahili as official language. Tanzania has a Human Development Index (HDI) of 0.528 ranking it 159 out of 189 countries (United Nations Development Programme, 2019) making it one of the least developed countries in the world. Tanzania has extensive environmental problems with water pollution and poor treatment of solid and liquid waste (Central Intelligence Agency, 2020). Furthermore, indoor air pollution due to wood and charcoal fuel used for cooking and heating is a common environmental health issue. There are also problems with deforestation and poaching which in turn leads to loss of biodiversity.

Figure 1. Map of Tanzania with Mwansa district in red (Sémhur, 2009, CC-BY-SA-3.0).

Just above half of the rural population has access to improved drinking water sources and only 30 % have access to improved sanitation (Central Intelligence Agency, 2020). Of the total population almost 70 % of the population has access to improved drinking water and almost 50 % to improved sanitation. Open defecation is a frequent problem and the risk for sanitary diseases is very high.

The village Bulyaheke, that is the focus area of this project, is located in the Mwanza region in northern part of Tanzania, adjacent to the shore of Lake Victoria, see Figure 1. Mwanza is one of the poorest and most densely populated regions in Tanzania with about 2.8 million people living in the area in 2012 (United Nations Population Fund, 2012). In Bulyaheke village lives about 5000 people but the adjacent rural area to the village has a population of about 35000.

The main livelihood in the region is agriculture and fishing along the shores of Lake Victoria. The growing and developing population generates more industry, agriculture and transportation in the region (Augustsson & Nylund, 2020). This together with the lack of wastewater and solid waste management generates an increasing pollution of Lake Victoria and other watercourses, which in turn reduces access to clean water for the people living near the shores. For instance, more than 90 % of the schools in the area lack sufficient handwashing facilities for their students.

The climate in Mwanza region is subtropical with generally high temperatures and regular precipitation. The temperature has a yearly average maximum of 27 °C and minimum of 17 °C (Weather & Climate, 2019). The warmest month is August, and the coldest month is January. The yearly average precipitation is about 1120 mm and there is a dry period in the summer extending over June, July and August. The monthly average precipitation is illustrated in Figure 2.

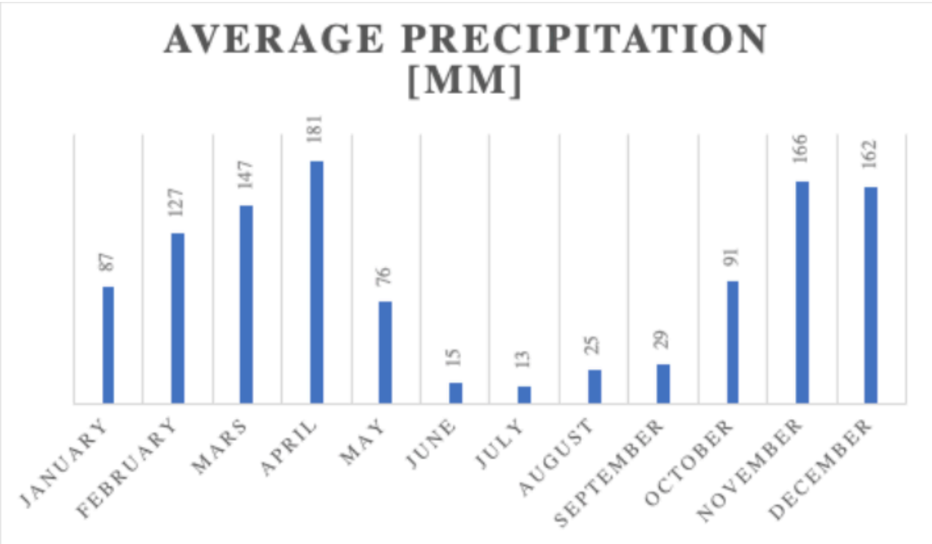

Figure 2. Average monthly precipitation over the year in Mwanza region (Augustsson & Nylund, 2020).

The most common soil in the area is a mixture of clay, silt and sand, sometimes with large rocks making it hard to excavate (Augustsson & Nylund, 2020). The ground has ability for water storage in isolated aquifer structures, primarily in unconsolidated sand and gravel formations. However, the high evapotranspiration due to high temperature together with the dry crust of the ground do not allow for a lot of groundwater recharge. The depth of groundwater level in Bulyaheke is not known.

In the village there are two schools, Bulyaheke Primary School and Mandela Primary School, adjacent to each other (Augustsson & Nylund, 2020). They are located just south of the village centre and there is approximately 1.5 km to the shore of Lake Victoria, see Figure 3. Together the schools have about 4100 students within the age of 5 to 19 years old, with a fairly even distribution of boys and girls. There are at least three students with physical disabilities at the schools. At the schools some crops, mainly corn and cotton, are grown to create a source of income for the schools. The schools do not have a kitchen and do not serve any food to the students. The students do not attend school during approximately two months in the middle of the dry period.

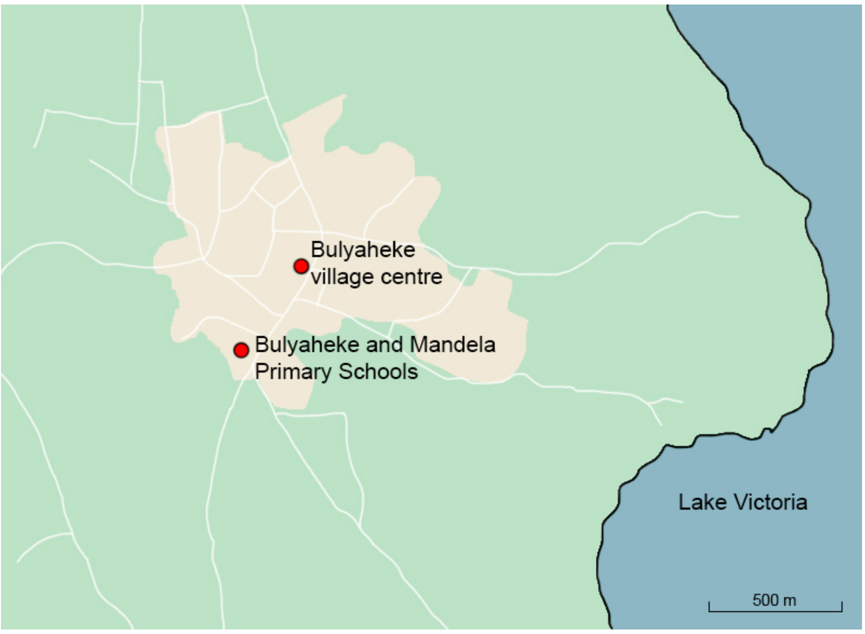

Figure 3. Map of Bulyaheke village and the location of the schools.

The two schools share toilet facilities which today consists of six Ventilated Improved Pit (VIP) latrines, three for the girls and three for the boys, and two similar toilets for the teachers (Augustsson & Nylund, 2020). Neither the students nor the teachers have access to any handwashing facility at the school. The teachers and students together clean the toilets each morning and the students bring water from their homes for this purpose. However, the toilets are rarely clean, the floors are uneven which allows for puddles of water, urine and faeces, see Figure 4. The brought water does not cover the need, neither in terms of volume nor of quality. The toilet facilities are reported to have a strong odour, and many children prefer to hold and go to toilet at home or elsewhere. Some of the toilet stalls do not have doors and the ones with doors are not possible to lock, which makes them unsafe to use. It is uncertain how the students clean themselves after toilet visits, the preference is toilet paper or anal cleansing water, but neither alternative seem to be available. In the region generally squatting is preferred over sitting while defecating. Squatting is normally also practiced by men for urination. Standing urinals are not common in the area but may be accepted, however these are not further considered in this study. The preference is to have separated toilets for men and women.

Figure 4. Left: Inside the girls' toilet with squatting commode, uneven floor and water bucket. Right: The boys' toilet stalls with uneven floors and lacking doors (Augustsson & Nylund, 2020).

The Tanzanian government have in collaboration with UNICEF developed guidelines on school water, sanitation, and hygiene (SWASH) (Ministry of Education Science and Technology, 2016). These guidelines emphasise the importance of safe sanitation in schools, that the solutions are sustainable and accepted by the users and the importance of community involvement for a sense of ownership and local commitment. They have a target standard of one toilet per 20 girls and one toilet per 25 boys in the schools, however the recommended toilet ratio for urgent needs is 40-50 students per toilet. In this study, as in the previous one by Augustsson and Nylund (2020), it is therefore recommended to use a median value of one toilet per 45 students, resulting in a recommendation of at least 92 toilets to be built at the two schools. The SWASH guidelines recommend having at least one handwashing facility per 100 students.

The interviews and observations by Augustsson and Nylund (2020) show that the students both have knowledge and ongoing education on sanitation and hygiene two times a week, nevertheless they keep getting stomach-aches and other diseases. This shows that knowledge is not enough but there need to be adequate sanitation and hygiene facilities for the situation to improve.

2.2 Sanitation

Since July 2010 the United Nations (UN) recognizes "the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights" (United Nations General Assembly, 2010). During that same year UN estimated that 2.6 billion people lacked basic sanitation and that 884 million people did not have access to safe drinking water. Furthermore, the number of children below 5 years old that died from sanitation related diseases was estimated to

1.5 million per year and the number of school days lost each year was 443 million due to the same reasons. Recognizing safe drinking water and sanitation as a human right means that all states have a responsibility of working globally towards the goal that all humans have equitable access to water and sanitation. The UN Member States also committed to achieve the Millennium Development Goals between the years 1990 to 2015. Two of these goals were to halve both the number of people that do not have access to safe drinking water and to halve the number of people that lack basic sanitation.

The Millennium Development Goals regarding water and sanitation were reached and the goals were updated in 2015 to the Sustainable Development Goals (SDGs) (United Nations, 2020b). These new goals were adopted by the international community and are to be reached by year 2030. Goal number 6 is named Clean Water and Sanitation and the content in short is that all people should have access to safe drinking water, to end open defecation and achieve safe sanitation and hygiene for all (United Nations, 2020a). The goal states that these assets should be equitable and affordable for all people, with particular consideration to the needs of women and those in vulnerable situations. Furthermore, the goal is to use water more efficiently and reduce water scarcity, decrease water pollution, halving the release of untreated wastewater and protect ecosystems associated with water. The goal is to be reached through international cooperation and the involvement of local communities.

Now in the year of 2020 the global sanitation situation continues to improve but is far from reaching the SDGs by 2030 (UNICEF & WHO, 2020). The development is too slow and need to move four times faster to reach the goals in time. Nevertheless, open defecation has decreased from being practised by 21 % of the world population in year 2000 to 9 % in year 2017. During the same time period, the proportion of the population with access to basic sanitation has grown from 56 % to 74 %. However, in year 2017 only 45 % of the world population had access so safely managed sanitation. In 2019, 37 % of the schools in the world had none or only limited sanitation facilities, which means that almost 700 million children lack basic sanitation at their schools. In Sub-Saharan Africa only 47 % of the schools have access to basic sanitation.

2.2.1 Safe sanitation

A safe sanitation system contains of several steps, called the sanitation service chain which consist of capture, containment, emptying, transport, treatment and safe disposal (UNICEF & WHO, 2020). There are several different variations and combinations of this chain over the world, and the waste can either be treated and disposed on site, temporarily kept and then treated after transportation to a treatment facility or carried through a sewer system to a wastewater treatment plant. Correctly managed and treated human waste can be turned into an asset, e.g. as fertiliser where significant nutrients, minerals, energy and water can be returned to the cycle of nature.

Poor sanitation can lead to a number of diseases and health problems. Some of the common sanitary diseases are diarrhoea, cholera, stunting, neglected tropical diseases, anaemia leading to premature births or spontaneous abortion, antimicrobial resistance and vector-borne diseases (UNICEF & WHO, 2020). Many of these diseases are most severe or a common cause of death for children under five years.

These diseases, caused by bacteria, viruses and parasites can be spread either through direct contact with human waste, indirectly through drinking or contact with water, eating food and contact with soil, or through vectors and other carriers (Winblad & Kilama, 1978). It is therefore essential to safely treat and dispose human waste, without any direct contact to humans or contamination of soil and water sources. Personal hygiene, like handwashing, safe handling of foods and reduction of vectors and flies is also important to reduce the risk of diseases.

Furthermore, poor sanitation can have a negative effect on economy, dignity, safety, equality and education (UNICEF & WHO, 2020). Women, girls and people with disabilities are particularly affected by poor sanitation, which reinforces the large gaps in equality in many societies. As a woman it is hard to manage menstrual hygiene in a safe and dignified way without adequate sanitation facilities. This also affects the school attendance of girls, if they do not have access to facilities to manage menstrual hygiene they may need to stay at home during menstruation and risk losing a fourth of their education time. However, investing in safe sanitation systems have shown to create a number of positive effects throughout communities and it is estimated that the financial profits are five times greater than the investment cost of sanitation facilities (UNICEF & WHO, 2020).

To safely manage human excreta and consider it an asset where the nutrients are recycled back to nature is an important part of the EcoSan concept (Schönning, 2001).

2.2.2 Characteristics of human excreta

The characteristics of human excreta are important when estimating the need for water and other additives for the toilets, such as ash, sawdust and straw, and when calculating the sizes of tanks and pits. According to a literature review by Rose et al. (2015) there is a significant difference in the median wet weight of faeces between high-income and low-income countries, 126 g/cap/day in high-income respectively 250 g/cap/day in low-income countries. However, the individual variance is large, ranging from 51-796 g/cap/day. Total food intake, body weight and diet are the main aspects affecting faecal production. The higher wet faecal weight of low-income countries compared to high-income ones is mostly affected by the generally large difference of dietary habits, where people in low-income countries tend to eat more fibres and resistant starches which increase the wet faecal weight. Similarly, urine production is dependent on body size and water balance, with mean values of 0.6-2.6 L/cap/day. The urination frequency differs a lot based on fluid intake and health, ranging from 2 to 11 times over a 24-hour period.

The main components of faeces are water, protein, undigested fats polysaccharides, bacterial biomass, ash and undigested food remains (Rose et al., 2015). In Table 1 the most important characteristics of human excreta are shown, and these are also the values used for the calculations in this report.

Table 1. Human excreta characteristics (Rose et al., 2015).

Parameter	Average values
Faeces production, wet weight, low-income countries	250 g/cap/day
Faeces production, wet weight, children 3-18 years	225 g/cap/day
Faeces density	1.06 kg/L
Stool frequency	1.10 motions/day
Stool frequency, children	0.975 motions/day
Faeces C:N ratio	7:1
Faeces water content	75 %
Urine production	1.4 L/cap/day
Urine production, children	0.94 L/cap/day
Urination frequency	6.5 motions/day
Urine C:N ratio	0.8:1

2.3 Solution alternatives

Below the two alternative solutions are described to be able to compare the two. First the previously recommended Fossa Alterna is described and then a biodigester with biogas production which was suggested as a solution by EWB-SWE is presented. The solution for urine treatment is then presented in its own chapter since both solutions are urine diverting toilets (UDT) and the urine would thereby be handled in the same way for each alternative.

2.3.1 Fossa Alterna – double pit UDDT

The previous study by Augustsson and Nylund (2020) suggested to build Fossa Alterna toilets att the schools. This solution was recommended since it does not require water for flushing, which is favourable with the current scarce water situation at the schools. The decomposed effluents can be used as fertiliser for the school crops and the construction and maintanance is realtively easy. Furthermore the stalls can be lighted which increase the safety and utility, especially for children, in contrast to a VIP latrine that has to be kept dark.

Fossa Alterna means alternating ditch and is the name of a urine diverting dry toilet (UDDT) with double pits. This implies that urine and faeces are separated in the commode and the faeces from one toilet unit are stored in two pits, where only one is used at a time (Monvois et al., 2010). When the first pit is full, it is sealed and left to dry and decompose, and the other pit is taken in use. When the second pit is full, the first pit is emptied and then used again, and so the process continues in cycles, see Figure 5.

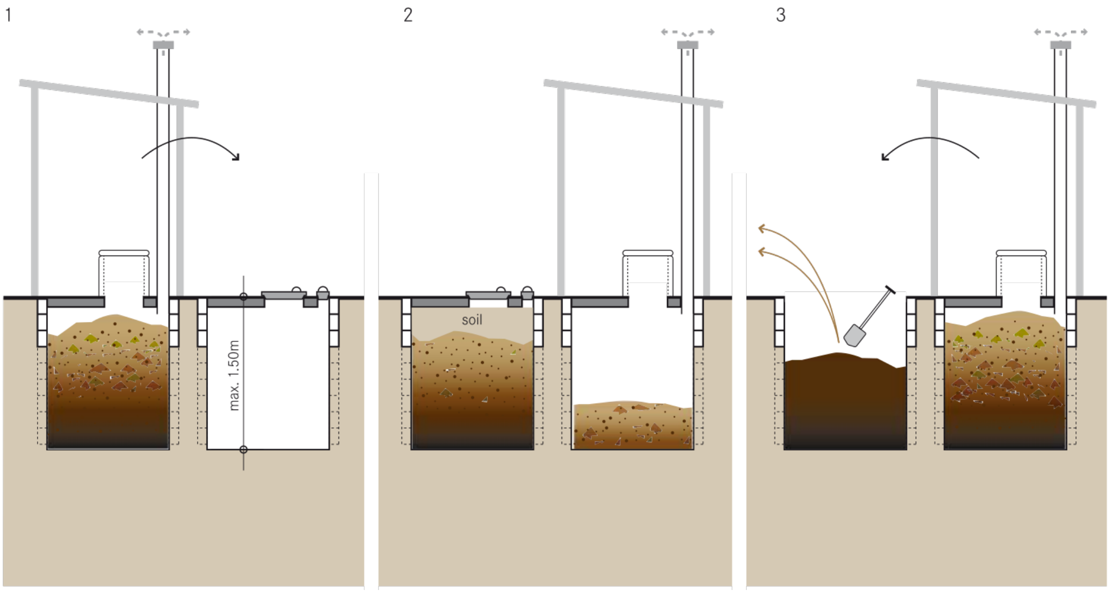

Figure 5. Process of a double pit compost toilet (EAWAG, 2014, CC-BY-3.0).

Each pit need a ventilation pipe and an easily accessible emptying hatch (Monvois et al., 2010). Above the pits there is a slab with commode and a privacy stall, these structures can be constructed in a few different ways. The commode could either be designed for sitting or squatting defecation, the important thing is that it is urine diverting and no water access the faeces pits, since these should be dry. The urine should be led through a pipe to either urine storage or a soakaway. The stall could be constructed by several different materials depending on availability and the desired life span. It could either be constructed to be moved to the pit in use each time the pits are changed, as in Figure 5, or to cover both pits with one stall. Alternatively, one stall can be constructed for each pit.

The faeces in a Fossa Alterna are sanitised by composting which is a biological process where organic substances are decomposed anaerobically and pathogens are inactivated through high temperatures, unfavourable pH, competition for nutrient, antibiotic action, toxic by-products of decomposing microbes, and desiccation (Mehl et al., 2011; Monvois et al., 2010). The organisms required for composting do not need to be added since they already exist in organic material (Winblad & Kilama, 1978). However, different pathogens have different conditions where they are inactivated or destroyed. Furthermore, some conditions that are favourable for the pathogen destruction process, like low water content and high pH, are unfavourable for the composting process, which creates conflict in the maintenance of the latrines (Mehl et al., 2011). The decomposed matter can be used as fertiliser and soil conditioner, and thereby recycles the nutrients to nature. To optimise the decomposing process, the faeces need addition of other organic material. This can consist of kitchen scraps, straw, leaves, sawdust, bedding material etc. Addition of these materials and/or ash, soil and lime after every use also reduce the risk of odour from the pits (Winblad & Kilama, 1978).

A natural compost contains both aerobic and anaerobic microbes, usually the processes close to the surface are aerobic while in the middle of the pile it is anaerobic (Winblad & Kilama, 1978). Aerobic condition is favourable in this kind of compost since it is a faster process and generates more heat which is better for destroying pathogens.

Anaerobic conditions may also release odorous gases like hydrogen sulphide and ammonia. If there is a lot of anaerobic process in the pit the compost can become acid. Too low pH is not good for decomposing microbes and the addition of ash and lime can help to increase the pH again.

The addition of the other organic materials favours aerobic conditions since it creates air pockets, which also are made by worms and insects in the compost. Another way of aerating the material is by turning, however this is not recommended in this case since it would involve manual handling of the un-sanitised faeces which would not be safe. It is also important to keep the moisture content low enough, otherwise it risks compacting the material and filling the voids with water instead of air. Therefore, it is essential that the toilet is urine diverting and that no cleansing or other water is added to the faeces. Nevertheless, the moisture content should not be too low either, since the microbes require water for survival. However, the natural water content of faeces is about 75 % (Rose et al., 2015) and the recommended moisture content for compost is 50-60 % (Winblad & Kilama, 1978). With some addition of dry material and some evapotranspiration the moisture content should be in a good range, but should be monitored and more water respectively dry material should be added if necessary.

The ratio between carbon and nitrogen, C/N ratio, in the compost is also important for the decomposition rate. Microbes feed on both carbon and nitrogen but requires more carbon than nitrogen and a C/N ratio of 15-30/1 is ideal for efficient decomposition (Winblad & Kilama, 1978). The C/N ratio of faeces is about 7/1 and for urine about 0.8/1 (Rose et al., 2015). This means that urine diversion is favourable for the C/N ratio and addition of other organic material too, e.g. straw has a C/N ratio of about 100/1, sawdust of 350/1 and non-legume vegetables of 15/1.

Given that the latrine is managed by the recommendations above, when the faeces have been stored for at least six months after the last use, most of the pathogens have been destroyed and it is safe enough to empty the pit and safely dispose the compost (Mårtensson, 1996; Winblad & Kilama, 1978). The compost should feel fairly dry, be odourless and soil-like. However, some pathogens, especially protozoa and helminths, may have survived and the manual handling should be minimised, personal safety equipment, like gloves and face masks, should be worn and children should be kept way. Neither should crops that grow on the ground and/or are eaten raw be fertilized with this compost to reduce the risk of pathogen contamination (Mehl et al., 2011).

The composted faeces can then be used as valuable soil conditioner and fertiliser for agriculture, improving the water bearing abilities of the soil and increasing the organic content (Winblad & Kilama, 1978). If there is no need or possibility to use the compost as fertiliser it should be excavated in the ground and covered properly, with sufficient distance to any water sources.

Summarised below are some important criteria to consider when designing a Fossa Alterna (Monvois et al., 2010).

- The pit size should be adapted to the number of users and required retention time (six months).
- The retention time may need to be modified if the decomposition is unsatisfactory.

- The composition of nitrogen, carbon, air and moisture needs to be balanced in the compost.
- No urine, water or other liquids should be added in the faeces pit. Nor any insecticides, pesticides, cleaning products or similar chemicals, since this might kill the decomposing microbes.
- No inorganic waste, like menstrual pads or plastic litter should be thrown in the pit, this shall be collected in a dustbin and incinerated.
- The users must be educated on how to use the Fossa Alterna in a correct way.
- At least one specific person should be assigned the responsibility to ensure the function and correct maintenance of the system.

The regular maintenance consists mainly of:

- Daily cleaning of the stall and commode. Emptying of dustbins.
- Addition of kitchen scraps, plant residue, straw, leaves, sawdust, bedding material, ash, soil, lime etc. after every use or at least every day.
- Regular cleaning of urine pipes with small amounts of hot water to reduce clogging.
- Monitoring the compost moisture content and temperature should be done regularly.
- When the pits start to fill up, the top of the faeces pile might need to be pushed down and evened out with a stick or spade through the faeces hole.
- Manual emptying of the decomposed faeces and change the pit in use every six months.
- Reparation and other maintenance of stalls, doors, pit construction, pipes etc.

2.3.2 Biodigester with biogas extraction

A biodigester is a facility where excreta and other organic material is decomposed, or digested, through anaerobic process where biogas is produced by methanogenic bacteria (Meynell, 1976). A biodigester was suggested as a sanitation solution for the two schools in Bulyaheke by EWB-SWE. This suggestion was based on the expected advantage that the biogas can be used as a source of energy for the school, possibly converted to electricity or being a source of income for the school.

There are several different ways of designing a biodigester, however the principle and components are generally the same. Biodigesters have commonly been used since the early 20th century as one of the steps in a conventional wastewater treatment plant, but it is also possible to construct small digester for household use or larger ones for digestion of excreta at large animal farms (Meynell, 1976). The general processes of a digester commonly used for situations similar to the one in this project are described below.

The excreta and other organic material are mixed with water to required consistency in a mixing chamber, see Figure 6, and then allowed to digest in the air-tight digestion chamber during one to three months, depending on the composition of the influent and environmental conditions (Meynell, 1976). The digestion chamber has a biogas pipe on top collecting the gas produced and leading to gas storage or to direct use. After the digestion chamber there is an expansion chamber that collects the excess slurry. The effluent from the digester needs secondary treatment, however it is often enough for it to be stored and/or dried for at least six months and then be used as fertiliser and soil conditioner similar to the compost from the Fossa Alterna, or safely disposed of. However, there might still be some pathogens in the effluent and the handlings should be minimised and done with care (Avery et al., 2014). It is also not recommended to fertilise crops that are to be eaten raw or grow on or in the grounds with the effluent. Since the biodigester is a sealed system there should not be any odour problems.

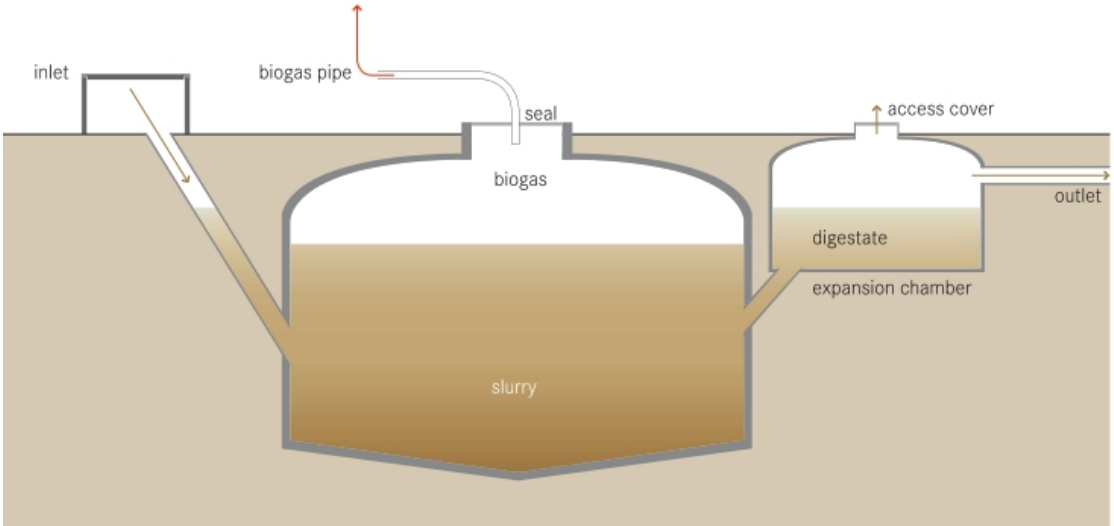

Figure 6. Schematic of a biodigester (Tilley et al., 2014, CC-BY-SA-3.0).

The main components of the biogas produced by the digester is 55-70 % methane and 30-45 % carbon dioxide, but can also consist of various smaller amounts of hydrogen, carbon monoxide, nitrogen, hydrogen sulphide and oxygen (Deublein & Steinhauser, 2008; Meynell, 1976). For the biogas to be combustible it needs to have a methane content above 45 %, which also means that the biogas poses a fire hazard in the presence of oxygen. The biogas can be stored in gas tanks with or without pressure, and used for heating, lighting or cooking fuel. The biogas can also be converted to electricity, e.g. with a Sterling motor, or used as fuel for a combustion engine.

The anaerobic methanogenesis process consists of three phases (Avery et al., 2014). First the complex organic substrates, like polysaccharides, proteins and lipids, are degraded to simple sugars, amino acids and fatty acids through hydrolysis. Secondly these simpler organic compounds are transformed to carbon dioxide, acetate and hydrogen in the acid production phase and lastly the methanogenesis phase converts the carbon dioxide, acetate and hydrogen to methane and carbon dioxide and bacterial proliferation.

Almost all organic material will digest to some extent, however the efficiency of the biodigester is affected by a number of factors and require a good balance of the influent, both in terms of physical and chemical characteristics. Similarly to the compost process in the Fossa Alterna, the methanogenic bacteria require a C/N ratio of 20-30/1 to thrive (Meynell, 1976). It is therefore favourable to use urine diverting facilities for the biodigester solution as well, since urine have high concentration of nitrogen compared to carbon. Addition of material with high C/N ratio, like straw, sawdust, kitchen scraps or other plant residues, is also significant to raise the C/N ratio of the human faces and for the biodigester to work efficiently.

For the biodigester to produce a lot of biogas it is important that the nutritional value of the influent is high (Deublein & Steinhauser, 2008). The nutritional value of human faeces is not the highest, since the body has already made use of a lot of the nutrition. The addition of most other organic material, like plant residue, therefore, also increases the biogas yield from the digester. It is also important that harmful substances and trash are kept away from the biodigester, since these otherwise may disrupt the process.

Other factors that affect the biodigester process are temperature and acidity of the digestate. Anaerobic digestion is favoured between 5-55º C and the gas production rate increases (Meynell, 1976) as well as the pathogen inactivation increases with increased temperature (Avery et al., 2014). Therefore some digesters are heated, however that is not relevant in this case because of the amount of energy it would require, but the warm climate in Bulyaheke is by itself favourable for anaerobic digestion. The acidity or alkalinity can be measured by the pH value of the digestate. The acidity naturally varies during different steps in the digestion process, however, a well-functioning digester usually maintains a favourable pH between 7 and 8 by itself through several interacting factors (Meynell, 1976). Nevertheless, rapid changes in environmental conditions or other causes may make the digestate too acidic. If this happens the pH could be raised with addition of lime or the influent flow could be stopped for several days until the digester recover its balance (Meynell, 1976).

The moisture content of the influent is important for mainly two reasons. The first being that the consistency of the influent needs to be manageable so it flows smoothly through the pipes and chambers. For this purpose Meynell (1976) recommends a total solids (TS) content of 10 %, which corresponds to a water content of 90 %. To reach this value, 1.5 l of water need to be added to each litre of faces, if the moisture content of faeces is 75 % (Rose et al., 2015). The other reason is that too much nitrogen in the digestate can result in excessive ammonia concentration which can kill or inhibit the growth of the methanogenic bacteria. The nitrogen can be kept at a balanced level by carefully dosage of additional carbon, however it is easier to dilute the digestate with water. The nitrogen concentration should be below the toxic limit of about 0.3 %, but the digester will be more efficient if it is kept below 0.2 % (Meynell, 1976). This means that about 3 l of water is needed per kg of faeces. However these amounts of added water are calculated based on a digestate of only faeces and needs to be adjusted based on the other organic materials added to the digester.

Since some amount of water is needed for the function of the digester it is recommended that the toilets are designed with a pour flush model. This kind of toilet improves the user experience and allows for a water trap that reduces odour and prevents flies and other vectors to enter the digester (Monvois et al., 2010).

Summarised below are some important criteria to consider when designing a biodigester, some similar to the ones of the Fossa Alterna (Monvois et al., 2010).

- The digestion chamber size should be designed based on the influent volume, the solids loading rate and minimum retention time.
- The secondary treatment tank is designed from the effluent volume and retention time.

- The composition of nutrients, nitrogen, carbon and water needs to be balanced in the digestate and may need to be adjusted if the digester does not work properly.
- The urine should be diverted to separate urine treatment to lower the nitrogen content in the digestate. No insecticides, pesticides, cleaning products or similar chemicals should be added to the digester, since it might kill the methanogenic bacteria or disrupt the digestion process.
- No inorganic waste, like menstrual pads or plastic litter should be thrown in the digester, this shall be collected in a dustbin and incinerated.
- The users must be educated on how to use the biodigester toilet facilities in a correct way.
- At least one specific person should be educated and assigned the responsibility to ensure the function and correct maintenance of the system.

The operation and maintenance of the biodigester system consists mainly of:

- Daily cleaning of the stall and commode. Emptying of dustbins.
- Regular cleaning of urine pipes with small amounts of hot water to reduce clogging.
- Making sure that the poor flush system works correctly and adds a sufficient amount of water to the biodigester.
- Regular addition of organic material like straw, sawdust, kitchen scraps or other plant residues, to the digester in sufficient amounts.
- Checking for large pieces in the sludge that might disrupt the process or clog the pipes.
- Controlling the supply of influents and effluents.
- Monitoring sludge level and scum formation.
- Testing the pressure of the installation and make sure that the system sealed from air.
- Reparation and other maintenance of stalls, doors, chambers, pipes etc.

2.3.3 Urine treatment

Urine can be a valuable asset as fertiliser and contains a well-balanced combination of plant nutrients of a form that is easy for the plants to absorb (Schönning, 2001). Urine diversion also makes the faecal fraction dryer which reduces odour and can make it safer and easier to handle.

The urine is diverted in the commode and then led through a pipe to a tank where it is stored. It is preferable to flush the urine pipes with small amounts of water, preferably hot, each day to reduce the build-up of salts on the pipe walls. The urine pipes should not be made of metal, since it may react with the urine and create extensive build-up of corrosion and salts on the pipe-walls. The tank construction can vary greatly, from plastic buckets to large concrete chambers. However, the size of the tanks needs to be adapted to the number of users and the required storage time. Any manual handling of urine should be minimised before it is sanitised through the retention time. It is important to keep the tanks closed with as little contact with air as possible to avoid odour and nitrogen loss.

If the urine are to be used as fertiliser it is recommended to first be stored with a retention time of at least one month at 20º C (Johansson, 2000; Schönning, 2001). After this storage time the urine is safe to use as fertiliser for edible crops that will be processed and for fodder crops. If the urine is stored for over six months at 20º C it is safe to use even for crops that are consumed raw. However, for all edible crops it is recommended that the urine is mixed down or poured in small holes and groves in the soil rather than just irrigated on top, and that there is at least one month between the last urine spreading and harvest. The urine can be applied concentrated at a small distance, about 20 cm, from the plants to avoid burns on plants and roots and then water can be added to flush the nutrients into the soil (Schönning, 2001) or the urine can be diluted before irrigation with one part urine to 5-8 parts water (Mårtensson, 1996). For maximum fertilisation effect the urine can be dosed to about 1-1.5 l concentrated urine per day and square meter for most crops, which corresponds to a nitrogen addition of about 40-120 kg per hectare (Schönning, 2001). For some crops, like corn and fruit trees, the dosage can be increased three to five times.

If there is no need for the urine as fertiliser and the hydrogeological conditions allow for it, i.e. the groundwater table is low and there are no nearby water sources downstream of the toilets, there could be a urine soakaway where the urine is infiltrated into the ground instead of collected in a pit (Médecins Sans Frontières, 2010). The risk of spreading pathogens or polluting water sources is low if sufficient safety distances are kept. However, urine infiltration can lead to eutrophication of surrounding soil and water courses, due to the high concentration of nutrients in the urine. Nevertheless, infiltration is a better alternative than not managing the urine.

3 Methodology

The main method for this thesis is a literature study, which is further described in Chapter 3.1 below. After the literature was researched, there was an initial design of the two solutions with respect to the local prerequisites and the evaluation method, to be able to compare the two alternatives. The evaluation method is described in Chapter 3.2. When the evaluation was finished the chosen solution was further designed. The design method is described in Chapter 3.3. The workflow of this study is illustrated in Figure 7.

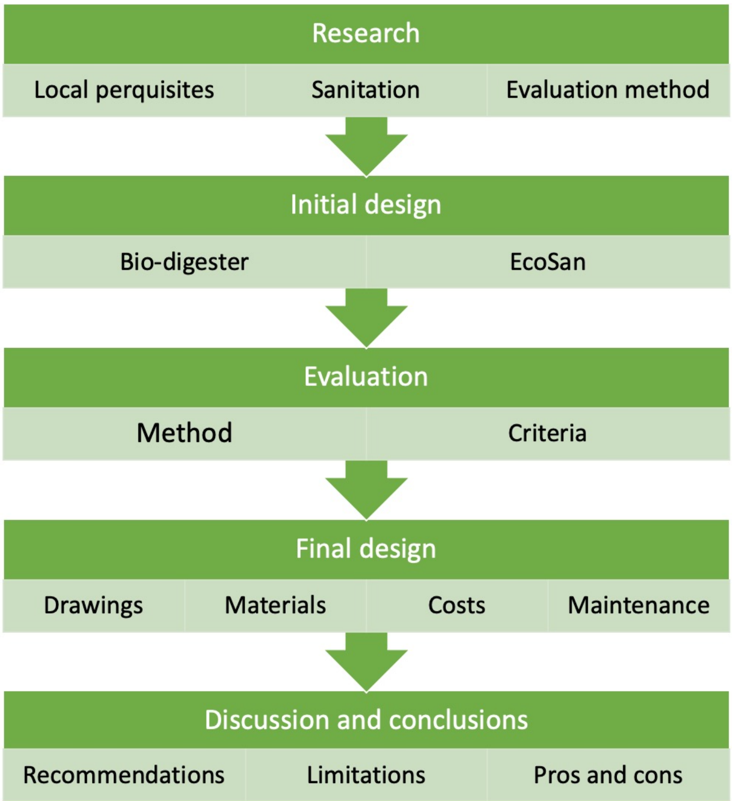

Figure 7. Overview of the methodology and workflow of this study.

3.1 Literature study

The literature study for this thesis is done with a qualitative approach (Ochieng, 2009). The literature was found through EDS: Chalmers library discovery system and Google Scholar, with use of the following search terms: ecological sanitation, biodigester, methane digester, human waste, human excreta, sanitation, biogas, WASH, urine diverting dry toilet, compost toilet, VIP latrines, RWH, public health, Mwanza Tanzania, and SDGs. The researched literature can be divided in three categories: sanitation, local prerequisites and evaluation methodology.

In connection with the initiation of the project EWB-SWE did a brief pre-study with an overview of the current situation and gathered some relevant literature on the subject, this pre-study was used as starting point for this study. Information about local prerequisites gathered during the study visits of the village and schools in Tanzania during the two previous master thesis studies is also used. Information from previous EWB-SWE projects was provided by EWB-SWE.

3.2 Evaluation method

The two toilet alternatives were evaluated and compared to see which solution is most suitable for the two schools. When choosing and designing a sanitation solution, it is important to consider the relationship between the human, environmental and technical parameter (Winblad & Kilama, 1978). The most important human factor is motivation. An unmotivated population will probably not use and manage a sanitation facility even if it is there. It is therefore significant that the users know how to use and maintain the facilities and know the importance of safe sanitation. Special consideration should be taken to social and cultural aspects for the solution to be accepted, and the local population should preferably be incorporated in the evaluation and the design process to create a sense of ownership, commitment and responsibility. The environmental parameter consists of local prerequisites such as groundwater, climate and geological conditions. The technical factor is the one that is adjustable, i.e., the design of the sanitation solution. There is no solution that works everywhere, it is therefore important that the solution design is well adapted to the environmental and human conditions.

To compare the two solutions, an appropriate evaluation method together with relevant criteria was selected. One criterium to take special account of is safety, both in terms of a safe sanitation solution, fire-safety regarding the biodigester and personal safety during usage of the toilet. The ambition was to include the FUO in the evaluation process to be able to have a solution that is well adapted to the local culture and prerequisites.

When researching evaluation methods for sanitation solutions, many methods that was found included user workshops or pilot-projects where several different solutions were built and then evaluated partly on trial-and-error. These methods probably generate results that are socially and culturally accepted and well established amongst the local population. However, they are time-consuming or require engaged people on site which was not possible due to Covid-19 or outside the scope of this project.

The evaluation of the solution alternatives was carried out using the three step process described by Monvois et al. (2010). This is a method that is well adapted to evaluation of sanitary solutions in developing countries, and it presents a comparable overview of the advantages and disadvantages of the solutions. The first step is to characterise the local sanitary conditions in physical, urban and socio-economic factors. This is practically already done by Augustsson and Nylund (2020) in the previous study. The second step is to determine a sanitation chain that suits the conditions characterised in step 1. This was also basically already done since the solutions that should be compared were already chosen. Step 3 is selecting the appropriate technological solution. This is done by comparing the solutions on 10 criteria and evaluating to which degree the characteristic of a solution fits the local conditions. The ten criteria are described in Table 2.

Table 2. Criteria for the evaluation method by Monvois et al. (2010).

	Criterion	Description
1	Acceptance by households and by local sanitation professionals	Qualified from low to high, depending on problems with the solution and easiness of use, resistance to take ownership of the facilities.
2	Lifespan of the infrastructure	Estimated lifespan of the solution, commonly ranging from 2-50 years.
3	The efficiency of the service put in place	The efficiency of the solution to maintain and use easily, to reduce handling of excreta, to evacuate solids and liquids, to which extent of treating the effluent.
4	Investment cost and operating cost	Either quantified in monetary terms, or qualified from low to high.
5	Design, construction and care and maintenance	This criterion covers the skill level needed for design construction, operation and to make sure the solution is working and maintained in good order.
6	Accessibility	Evaluates if the structure is accessible by trucks for vacuum cleaning (or tank-carts). Not relevant in this case.
7	Range	The range refers to the distance from the pits to the treatment facilities. Not relevant in this case since the treatment is on-site.
8	Electrical energy	Electrical energy required to operate the treatment facilities.
9	Required surface area	Can be quantified in square meters, or qualified from limited to large.
10	Water requirements	Can be quantified in litres or cubic meters, or qualified from low to high.

In addition to the criteria evaluated in the method above, the criteria in Table 3 were established and will also be considered when comparing the two solutions, to get a more holistic view.

Table 3. Additional aspects for evaluation.

Criterion	Description
Safe sanitation	How well does the solution treat excreta and reduce pollution of the environment? Is the required manual handling of excreta or effluents safe? Does the solution reduce the risk of sanitary diseases?
Personal safety	How safe is the solution to use and does it feel safe?
Added values	Does the solution have any additional values or benefits besides being a sanitation solution?
Adaption to local prerequisites	Can the solution be adapted to local prerequisites, like available materials, local skills and competence or water scarcity issues?
Risks	What kind of risks and hazards are associated with the solution?
Accessibility	Is the solution accessible for children and/or disabled people?

3.3 Design

The most suitable solution will be further designed, in terms of drawings, materials, estimated costs, maintenance requirements and tank dimensions. The design of the toilets is primarily based on the local prerequisites, the UNHCR guidelines on urine diverting dry toilets (2015), the Public health engineering guidelines by Médecins Sans Frontières (2010) and a previous EWB-SWE project in Karagwe, Tanzania (Burström, 2020). The size of the pits are based on the Tanzanian SWASH guidelines (Ministry of Education Science and Technology, 2016) together with characteristics of human excreta by Rose et al. (2015). The dimensions of the tanks are calculated based on the excreta characteristics in Table 1, the number of users, the retention times and standard geometric equations. The equations used for this and the calculations can be seen in the appendices.

4 Results

The Fossa Alterna is the recommended solution alternative for the Bulyaheke and Mandela primary schools. How this was concluded is described in the evaluation Chapter 4.1 below and the detailed design of the solution is described in Chapter 4.2.

4.1 Evaluation

The Fossa Alterna and biodigester solutions are evaluated and compared based on the evaluation method by Monvois et al. (2010) described in Chapter 3.2. The criteria characteristics are shown in Table 4 and the additional criteria in Table 5. The surface area and water requirements are calculated in appendices.

Table 4. Evaluation criteria according to the method by Monvois et al. (2010).

Criterion	Fossa Alterna	Biodigester
Acceptance by households and by local sanitation professionals	High, with exception of human excreta used as fertiliser	Medium, human excreta used as fertiliser and the advanced technology might be problems
Lifespan of the infrastructure	10-20 years for the toilet structure, 25-50 years for the pits	10-20 years for the toilet structure, 25-50 years for the digesters and tanks
The efficiency of the service put in place	High (no smells or flies; treatment of excreta; possible to use treated sludge as fertiliser)	High (no smells or flies; high level wastewater treatment; utilisation of biogas)
Investment and operating cost	219 698 583 TZS investment cost (Table 6), low maintenance cost	Unknown investment cost, but at least as expensive as the Fossa Alterna, higher maintenance cost
Design, construction and care and maintenance	Medium-level skills for construction, low-level skills for operation	High-level skills for construction, medium-level skills for operation
Accessibility	Not applicable	Not applicable
Range	Not applicable	Not applicable
Electrical energy	None	Electrical energy may be used for preheating or operating pumps or stirrers, but not necessary
Required surface area	565 m^2	557 m^2
Water requirements	None	1600 l/day

The two solutions are quite similar, however the Fossa Alterna solution has some advantages in terms of the higher acceptance prospect, the cost is estimated to be lower, it requires less skills for both construction and operation, and no water is needed for the function of the facility. Nevertheless, the biodigester solution has the advantage of utilisation of biogas as an energy source for the school or a possible source of income. The water required for the biodigester may cause a problem since the water availability is not constant and reliable. However, the theoretically available water of 6000 l/day from RWH (Chapter 4.2.7) covers more than the need of 1600 l/day for the digester. The water for the digester can first be used for the handwashing facilities and then recycled, to not affect the water availability for hygiene purposes. When calculating the surface area required for the tanks for the biodigester, a height of 2 m was chosen. If the tanks cannot be partially or completely excavated in the ground, this height might need to be reduced and thereby increasing the required surface area.

Table 5. Additional evaluation aspects.

Criterion	Fossa Alterna	Biodigester
Safe sanitation	The compost from the pit is sanitised but should not be handled more than necessary. It might be hard to keep the commode clean without any water getting in the pit. No flies or smells from a functioning system.	The effluent from the biodigester after secondary treatment is well sanitised with very low risk of pathogens. If the digester is disrupted it might need manual handling of excreta. No flies or smells from a functioning system.
Personal safety	The actual and the experienced personal safety is important but is more of concern regarding the toilet stalls, placement and exterior design. The two solutions have very similar external facilities.	
Added values	Compost used as fertiliser, however, excreta as fertiliser might not be accepted. Can work as pilot project/inspiration that is easily adjusted to household level.	Effluent as fertiliser, however, excreta as fertiliser might not be accepted. Valuable utilisation of biogas as energy source.
Adaption to local prerequisites	Can be constructed and repaired using locally available materials. Not necessary to have a constant source of water. Elevated pits, easier emptying and reduces risk of contaminating groundwater.	Can be constructed and repaired using locally available materials. Preferably excavated tanks for stability which requires a non-rocky layer several meters deep and a low groundwater level. Requires a constant source of water.
Risks	Risk of overflow if not emptied regularly. Water or other liquids in the pit disrupts the process.	Explosion or fire hazard due to biogas. Overflow and/or backflow, scum formation.
Accessibility	Similarly to the personal safety criteria this is mostly applicable to the external toilet facilities which are basically the same for the two solutions. However, this aspect should not be neglected when designing a solution and the facilities may need special adjustment to suit children and people with disabilities.	

Similarly to the evaluation Table 4, the additional criteria in Table 5 shows a lot of resemblances between the two solutions. The Fossa Alterna shows to be more easily adjusted to a household level, which makes it preferable in a pilot project with the intention of inspiring families to construct similar solutions themselves. Both solutions have the added value of using the effluents as fertiliser. This in turn can reduce the usage of chemical fertiliser and recycle valuable nutrients from the excreta that would otherwise be wasted. This is good for both the environment and economy of the schools, since it can increase the crop yields and save fertiliser costs. However, the use of fertiliser from excreta may not be culturally accepted.

The primary advantage of the biodigester over the Fossa Alterna is the utilisation of biogas as energy source. The biogas can replace liquefied petroleum gas (LPG) or firewood fuel, which in turn contributes less to the greenhouse effect, less deforestation and less smoke in the kitchen. However, since the schools do not have a kitchen and therefore no need for cooking fuel, which otherwise would be the obvious application for the biogas in this case, this advantage is no longer distinctly applicable. The biogas could be converted to electricity, but conversion causes energy losses and requires advanced technology and skill together with preferably large biogas yields which in turn require large amounts of organic additives to the digester, whose availability currently is not known. The effluent of the biodigester after secondary treatment is also regarded safer than the compost from the Fossa Alterna. However, the compost is regarded safe enough and this aspect therefore does not conquer the other benefits of the Fossa Alterna.

The recommendation based on this evaluation is therefore that the Fossa Alterna double pit urine diverting dry toilet system is the most suitable alternative for the Bulyaheke and Mandela primary schools. The solution is fairly easy to construct, use and maintain and is likely accepted by the students. The Fossa Alterna is considered to meet the requirements and be well adapted to the local prerequisites.

4.2 Design

The design, construction and material of the Fossa Alterna toilets are described in detail below. The toilets are put together in blocks of five toilets each. To reach the target of at least 92 toilets at the schools, corresponding to 45 students per toilet, a number of 19 blocks need to be constructed, resulting in a total of 95 toilets. The dimensions of the design are presented in the drawings. The calculations for the design are shown in appendices.

4.2.1 Toilet block design

The toilets are designed as blocks with five toilet units in each block. This saves some material in terms of fever outer walls etc. but also remains modular for the possibility of using the designs in other projects and places. The blocks consist of five toilet stalls with one door each, on top of the faeces and urine pits, see Figure 8, Figure 9 and Figure 10. The pits are in this case elevated, with only the base platform buried below ground, for easy access of emptying the pits through the backside hatches, but also to reduce the risk of groundwater contamination. If the groundwater level is low at the location where the toilets are to be placed, the pits can easily be modified to be completely or partially immersed in the ground, but the bottom of the pits should be kept at a minimum of 1.5 m above the groundwater level at all times. If the hydrogeological conditions allow for it and there is no use for the urine as fertiliser, there could be a urine soakaway where the urine is infiltrated in the ground instead of collected in pits.

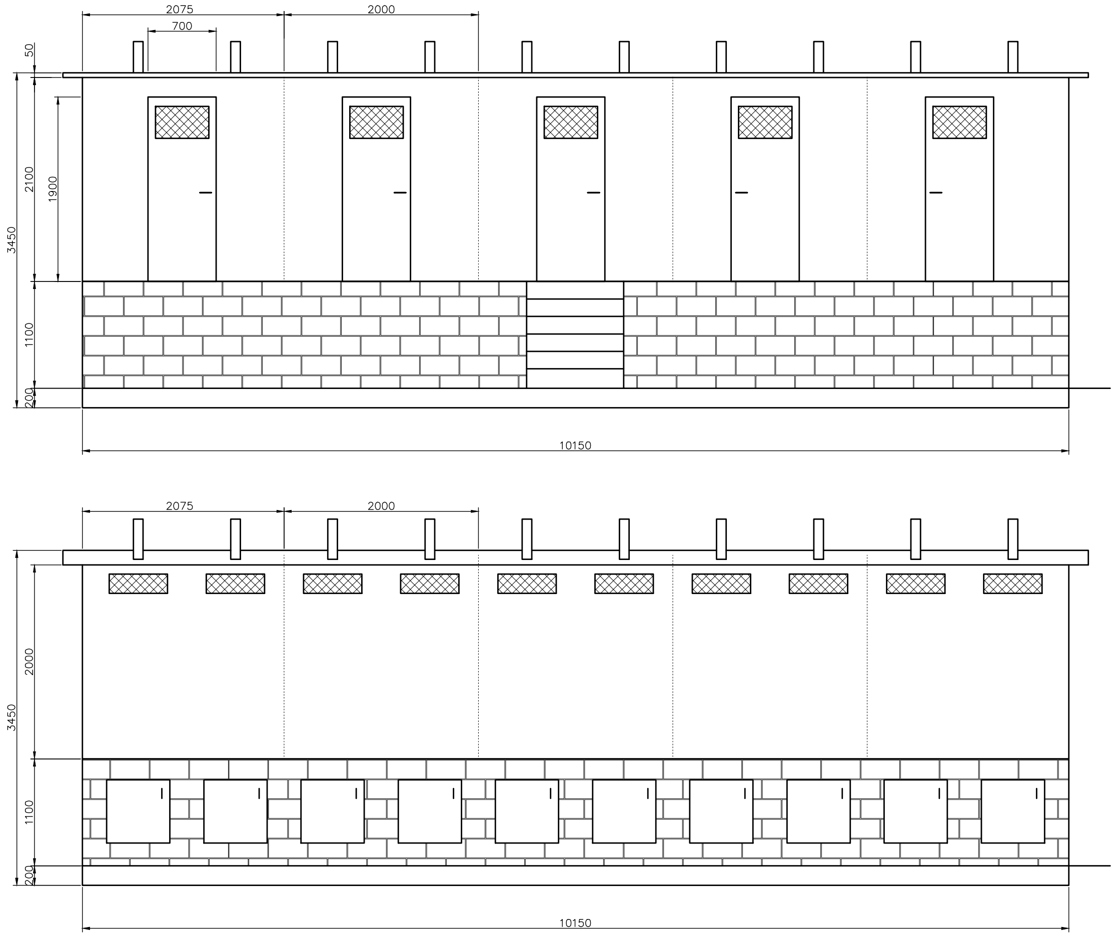

Figure 8. Front and back design of one toilet block, dimensions in mm.

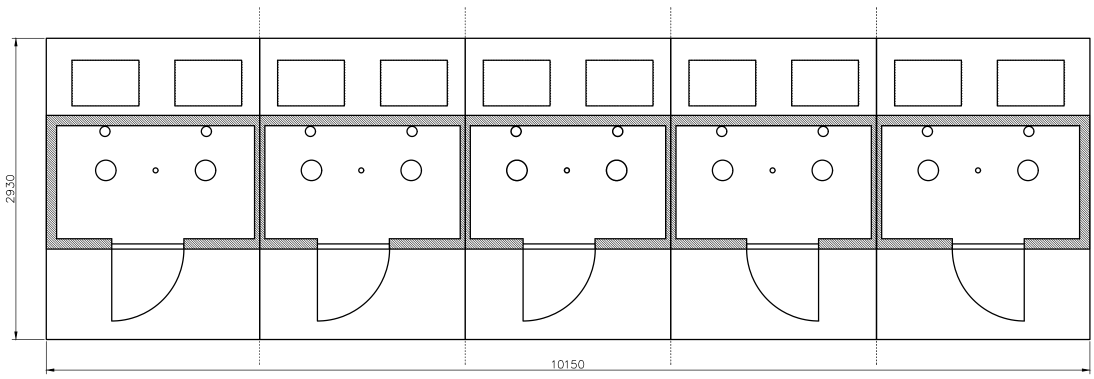

Figure 9. Overview of stalls in one toilet block. Each stall has two defecation holes, one urine hole, two ventilation pipes and two metal hatches that can be seen at the top of the drawing.

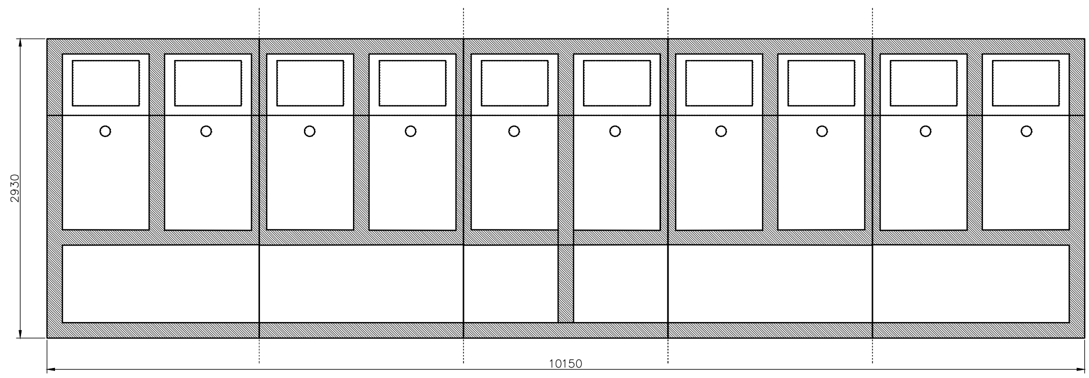

Figure 10. Overview of urine and faeces pits in one toilet block. The two urine pits are seen at the bottom of the drawing and at the top the ten faeces pits with their hatches and ventilation pipes are seen.

4.2.2 One toilet unit

A toilet unit consists of one stall but two faeces pits to be used alternately, see Figure 12. The urine storage consists of two alternately used pits per toilet block instead, which are shared by the five toilets in each block, see Figure 10. Each faeces pit has a sheet metal hatch on the backside to be used for emptying or other maintenance. These hatches should be locked, e.g. with a padlock or bolt and nut, at all times so the pits are not accessed by children or unauthorized people. Each faeces pit also have a ventilation pipe, attached to the back wall of the stalls, going up through the roof a bit above the highest point of the rooftop, see Figure 11 and Figure 12. The top of the ventilation pipe should be equipped with a flynet to reduce flies and vectors entering the pits and a cone-shaped lid to hinder any rainfall entering the pipe.

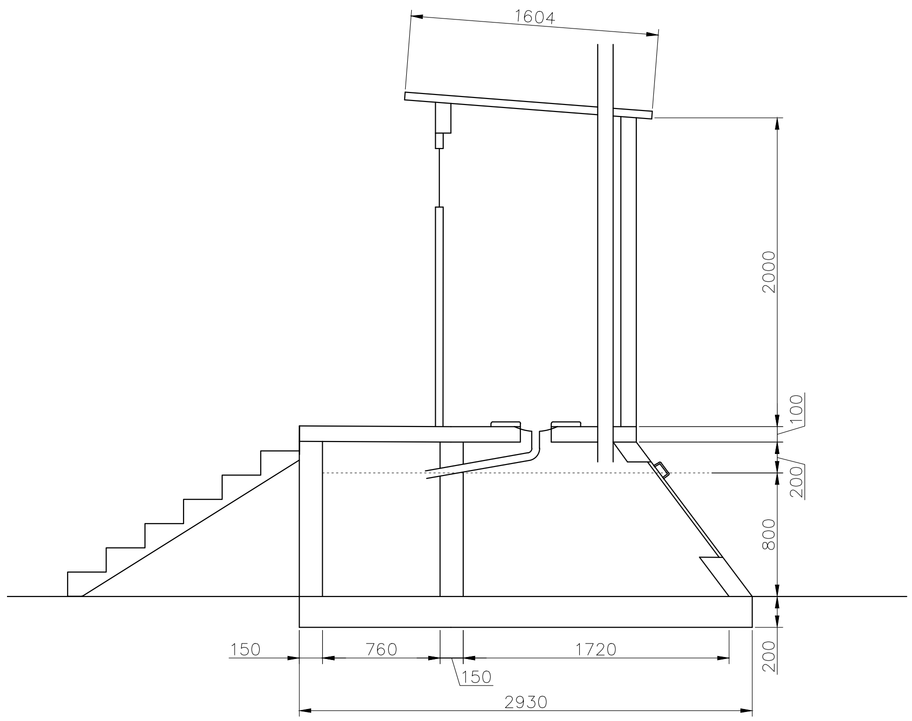

Figure 11. Section from the side of one toilet unit.

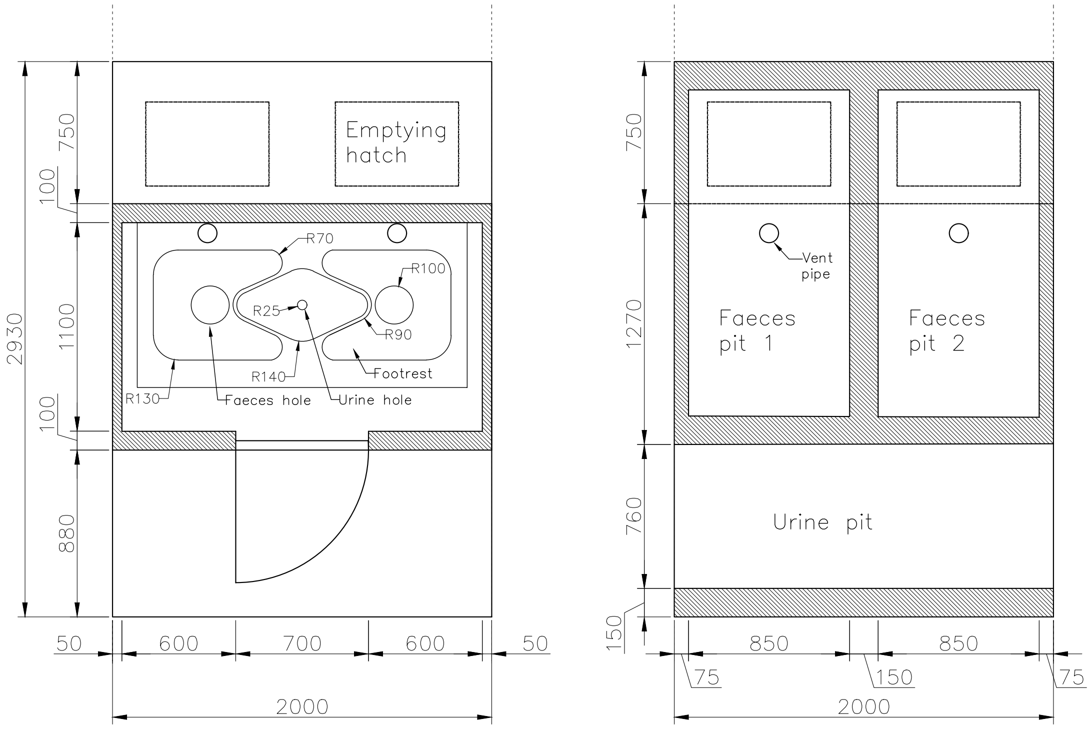

Figure 12. Details of one toilet unit. Left: stall and commode. Right: urine and faeces pits.

The base platform of the pits is excavated into the ground, where a levelled and even surface is prepared about 20 cm below ground level. Wooden or other sheet shuttering should be installed and levelled along the edges of the excavation to support the concrete casting. The excavation is then filled and compacted with approximately 10 cm of draining material, e.g. sorted gravel, and then a 5-10 cm thick concrete slab on top. The concrete slab should then be kept damp and out of direct sunlight for seven days during the first phase of the curing.

The pits are constructed of bricks with a cover of cement grout with a smooth non-absorbing inside surface to make them easy to empty and clean and to not leak out any contaminants to the surrounding environment. The corner bricks should be made with a Flemish bond for stability.

The squatting slab and floors are casted of reinforced concrete. To do so a temporary wooden cast mould is first built, the reinforcement is put in place and a template for the squatting slab and urine collection bowl can be made out of plywood or other sheet material. This template is then pressed down in the wet concrete and secured in place. The holes for faeces and urines can either be made with pipes of the right dimension or cylindrical wooden stubs that are removed when the concrete has cured. It is of absolute significance that the floors are levelled and completely even, to avoid any puddles of excreta when the toilets are used. It is recommended to scale down the squatting slab by about 10-20 % for some of the toilet stalls that are to be used by the smallest children. These toilets should also be equipped with a handle that the children can hold on to during defecation. How many toilets that should be adapted for small children need to be further evaluated based on the age distribution at the schools, which currently is unknown.

The outer walls of the stalls could be made of bricks, some kind of wood, sheet metal or other material depending on what is locally available, affordable and the desired lifetime of the structure. The inner walls between the stalls could with advantaged be constructed of thinner and cheaper material since they do not have the same exposure to whether and climate and not as vital to the mechanical strength of the construction.

The door should be able to lock from inside, e.g. with a hasp, and have a mesh-covered "window" to allow for light and ventilation but to reduce the risk of flies and other vectors accessing the stalls. The doors should be fastened to the wall by at least two hinges preferably placed so the doors are kept shut by gravity. The handles should preferably be placed so they easily can be reached by both small children and grown-ups.

The backside of the stalls has mesh-covered ventilation holes, if possible large ones to reduce any odour that may occur. Each stall is preferably equipped with electrical lighting, e.g. with a led light powered by solar panels on the roof. Since these toilets are mainly used during school-hours it is assumed that the daylight entering through the ventilation holes is sufficient for proper use of the toilets, but electrical lighting adds value for user-friendliness, safety and easier cleaning, especially for children.

4.2.3 Menstruation room

To assure the sanitary needs and safety for women and girls it is suggested to build a few menstruation rooms in addition to the toilets, see Figure 14. It is important for the doors to these rooms to be easily and securely locked from the inside. The menstruation rooms should have a water tap or water bucket and a floor drain connected to the urine pits, for personal cleaning and cleaning of reusable menstrual hygiene products. The drain could either be led to the urine tanks or to a soakaway. There should be a dustbin with lid for used disposable sanitary products. The dustbins should be emptied regularly or when full and the waste should preferably be incinerated. The ash from the incineration could then be used as additives to the faeces pits. It is recommended by previous projects to paint the menstruation rooms in bright colours and maybe colourful patterns to make some happier associations with the rooms and possibly reduce some of the taboos associated with menstruation (Burström, 2020). Building additional menstruation rooms would also mean that the larger number of toilets needed for women compared to men, would be reduced.

4.2.4 Disabilities

Since there are at least three students with physical disabilities at the school it is recommended to have either a removable elevated aid, something like the chair on the left in Figure 13, or to adapt one of the toilet units with an elevated commode and sturdy handles, as to the right in the same figure. This however needs to be further investigated together with the children in question and staff at the school, depending on the needs and what kind of disabilities the children have.

Figure 13. Left: Removable disability aid (SuSanA Secretariat, 2011). Right: Elevated commode and sturdy handles (Barrios, 2008).

4.2.5 Connecting the blocks in larger units

Since the recommendation is to build 19 of the five-unit toilet blocks at the school it is suggested that the blocks are to be placed in clusters, to save some surface area and some building material. The recommendation is to place two blocks facing each other with a roof covering the whole structure and privacy walls and stairs on the sides, see Figure 14. The roof can be inclined towards the middle, see Figure 15, which allows for easy RWH. This design is compact, material efficient and allows for easy access with the stairs on both sides. The two entries also provide an alternative way out if one of them were to be blocked by anyone or anything. The privacy walls at the sides should not go all the way to the roof, just high enough so it is not possible to see inside from the outside but preferably possible to see out over the walls from inside. This also allows for good airflow which reduces any odour. The clusters should be assigned to boys respectively girls separately, the female clusters should be equipped with a menstruation room. Handwashing facilities should be placed adjacent to the toilet facilities.

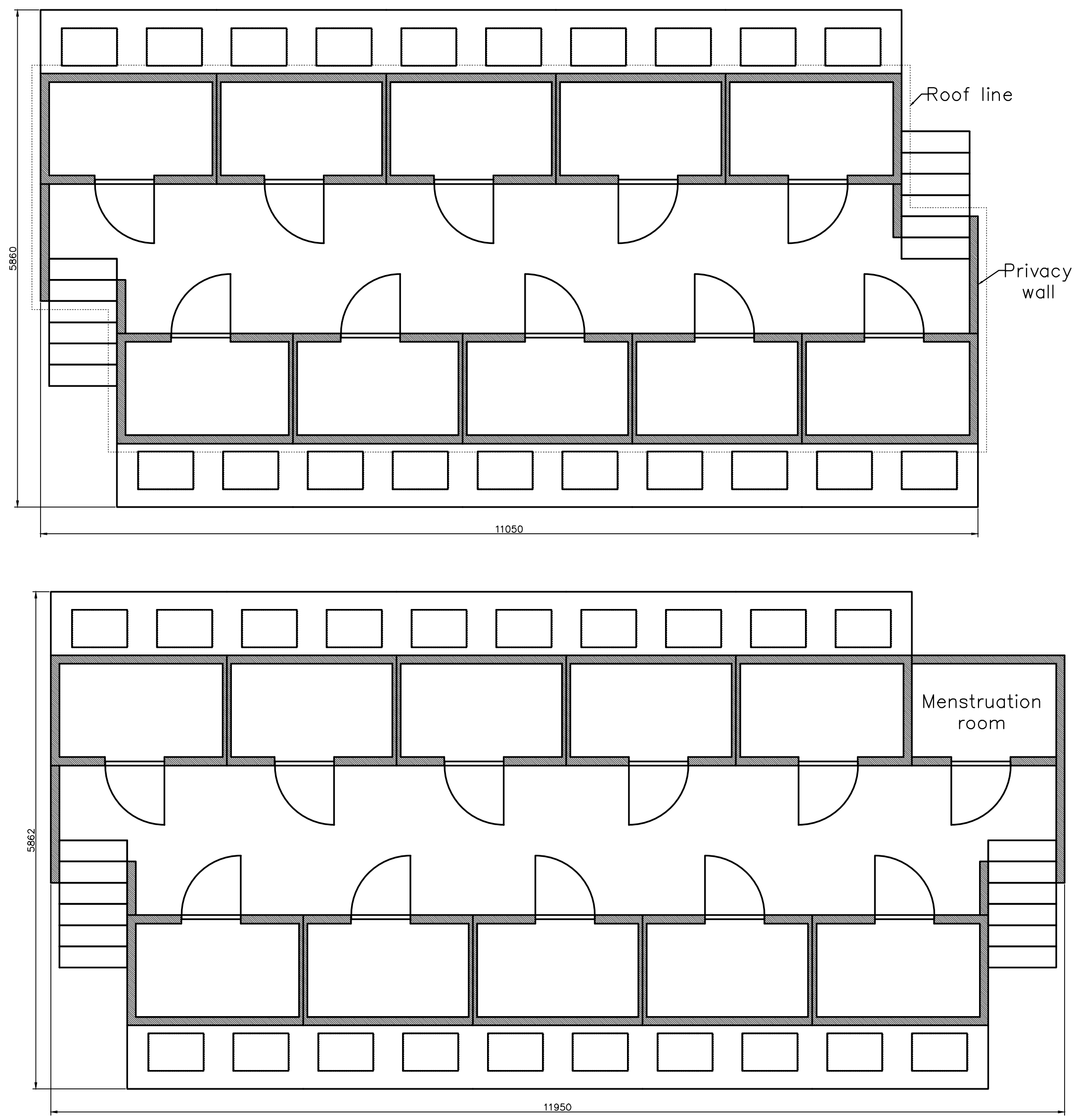

Figure 14. Suggestion for toilet block cluster. Menstruation room added to the top right in the lower drawing for female facilities.

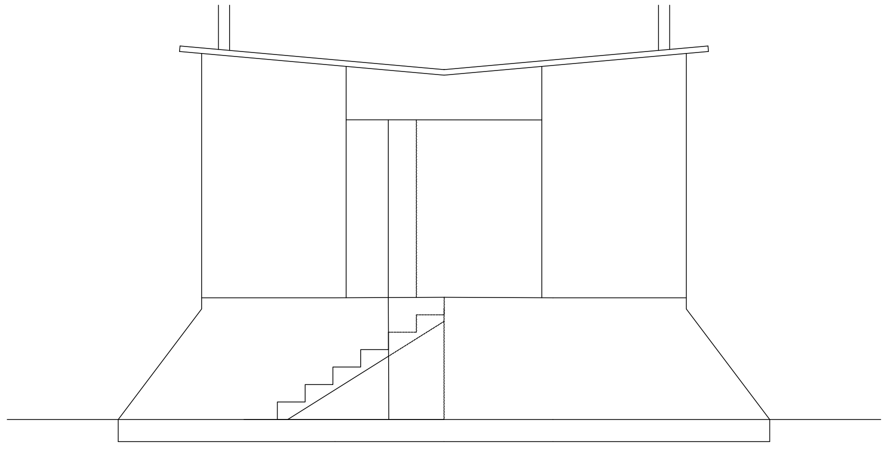

Figure 15. Side view of the toilet block cluster in Figure 14.

Another suggestion for a block cluster is to put three blocks in a U-formation, as illustrated in Figure 16. This design is based on the Karagwe school project (Burström, 2020) and allows for handwashing facilities in the middle inside the privacy walls. However, this formation takes up more surface area than the previous suggestion and with only one entry to the facility it risks becoming an unsafe environment.

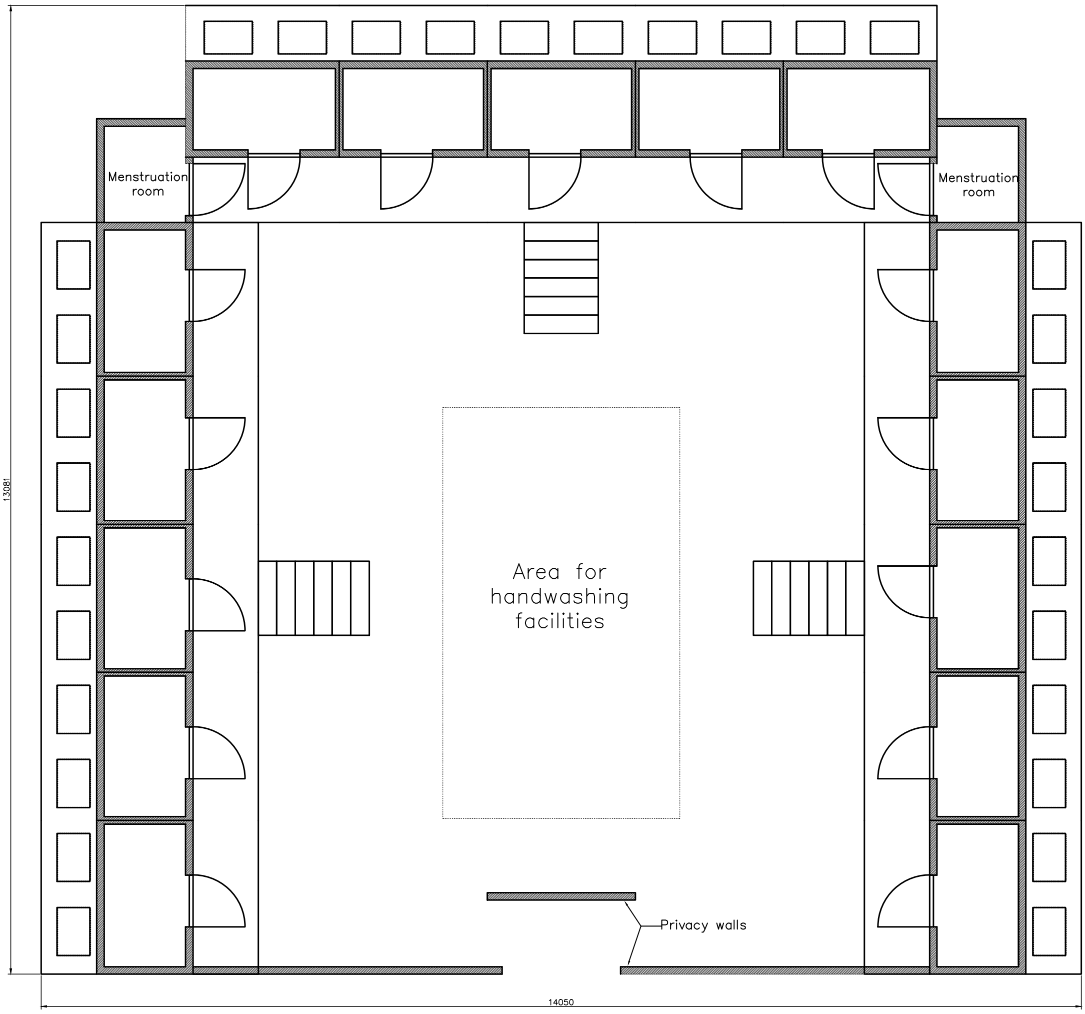

Figure 16. Another suggestion of block cluster. Added menstruation rooms in the corners.

4.2.6 Placement at the schoolyard

In Figure 17 an example of the placement of the toilet blocks in relation to the school buildings are illustrated. This illustration also gives a sense on how much space the different toilet block clusters take up in relation to each other and how much space all of the toilet constructions will take in relation to the school buildings. It is recommended that the clusters are placed at some different places around the school, so they are easily accessible from different places at the school and for all children.

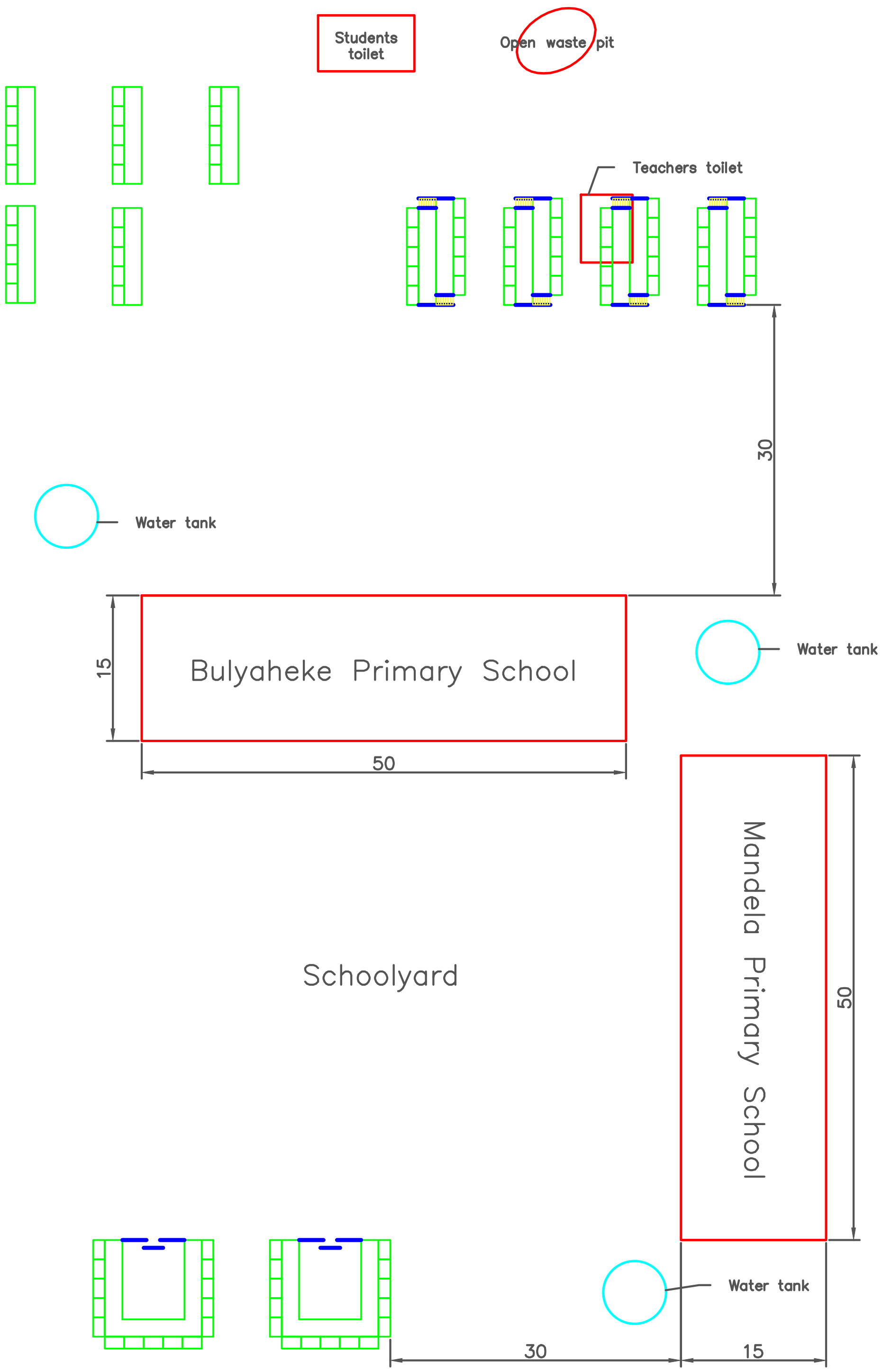

Figure 17. Overview of the schoolyard with example of toilet block placements. Existing buildings in red. Measurements in meters.

4.2.7 RWH and handwashing

RWH from the roofs of the school buildings is one of the recommendations by Augustsson and Nylund (2020) to improve the sanitary situation at the schools. The theoretically available water can be calculated by multiplying the roof area with the average precipitation, see calculation in appendices. In this case the theoretically average availability becomes about 4.6 m^3 water per day from the two school buildings and if the roofs of the new toilets are used as well, an addition of 1.4 m^3 per day can be harvested. This in total becomes about 6 m^3 water per day. However, the precipitation varies greatly over the year, with dry season from June to august, as described in Chapter 2.1. To create resilience in the RWH system and account for the differences in precipitation it is recommended to store the water in tanks that allows for the volume of the total average precipitation for one month. Then the tanks would need a volume of about 180 m^3, see Table A 3. In Figure 17 there is a suggestion of placement of the RWH tanks in relation to the school buildings. The three tanks are designed as cylinders of 6.2 m in diameter and 2 m high, giving them a volume of about 60 m^3 each, giving a total volume of 180 m^3. The RWH tanks should be covered to avoid vector breeding or contamination of the water.

It is recommended to use the first flush disposal method for the RWH, meaning that the first collected water of a rainfall is disposed, since this water contains the highest concentration of contaminants that have been accumulated on the roofs between the rainfalls. If this measure is taken and the roofs are cleaned regularly the water should be safe enough for handwashing and other sanitation purposes. For drinking or cooking purposes the water should be further treated, for example by boiling or with the SODIS method described in the previous study by Fransson and Werner (2019).

UNHCR recommends at least one handwashing dispenser per each five toilet units, located within 10 m of the toilet and easily accessible, especially for children (2015). In this case this corresponds to one handwashing dispenser for 225 students or 19 dispensers in total, which might be unreasonably few. In comparison the Tanzanian SWASH guidelines recommend one handwashing dispenser per 100 students (Ministry of Education Science and Technology, 2016), which in this case corresponds to 41 dispensers in total, and is viewed as the alternative that is recommended for the schools.

Furthermore, UNHCR recommends to use liquid soap or soap bar on a string that can be hanged so it does not become dirty or misplaced (UNHCR, 2015). They also recommend reducing the flow of the handwashing taps to 0.05 l/s to conserve water. Their estimation is that 0.5 to 1 l of water per person and day is needed for handwashing. This means that a total of about 2 m^3 of water is needed for handwashing at the two schools each day, if the lower number is chosen since the children are not at school their entire day. This leaves 4 m^3 per day of the theoretically available water, or approximately 1 l water per student and day, to be used for other sanitary purposes, or possibly drinking if further treated. However, a total availability of 1.5 l per student and day is a very low amount, compared to that the recommendation is to drink 2 l of water per day, even more in warm climates, and that the average Swedish person use about 140 l of water each day (Svenskt Vatten, 2019).

4.2.8 Operation and maintenance

As described in Chapter 2.3.1, one pit should be used until it is full or for at least six months, and then that pit should be sealed, and the decomposed pit should be emptied and then put in use. The decomposed faeces should be used as fertiliser for the school crops or be safely disposed. The urine pits will be used in the same way, with a minimum retention time of one month, as described in Chapter 2.3.3. According to the fertiliser dosage described there, the urine produced at the school is sufficient to continuously be used as sole fertiliser for a cultivated area of 1150 m^2, which corresponds to a square with sides the length of 34 m.

The maintenance consists of the list described in the end of Chapter 2.3.1, the most important considerations are the daily cleaning and addition of dry material after each use.

4.2.9 Costs

The cost of building 19 toilet blocks with a total of 95 toilets is estimated to about 220 000 000 TZS, which in 2019 year's exchange rate corresponds to 923 000 SEK, se Table 6. The design and labour costs are not included in these numbers, since it is assumed that this will be done on a voluntary basis, by EWB-SWE members, older students, students' parents and other dedicated inhabitants. This saves 21 % of the investment cost compared to the estimated cost if the labour was paid. In addition to the saving, community involvement in the implementation can also be beneficial since it creates a sense of ownership and responsibility of the facilities (Ministry of Education Science and Technology, 2016). The cost estimation is based on a previous EWB-SWE project in Karagwe, northern Tanzania, where one urine diverting double pit toilet together with one menstruation room were built at the Mavuno School during 2019. The costs are adapted to this project regarding estimated material needs and number of stalls, and some costs were cut since they were not relevant in this project.

Table 6. Estimated costs, based on costs in the Karagwe School Project (Burström, 2020). Cost in SEK calculated based on exchange rate of 2019.

Item	One toilet unit cost (TZS)	Toilet block cost (TZS)	Total cost, 19 blocks (TZS)
Bricks and concrete	1 319 000 TZS	6 595 000 TZS	125 305 000 TZS
Plumbing work	309 333 TZS	1 546 667 TZS	29 386 667 TZS
Metal and wood	244 333 TZS	1 221 667 TZS	23 211 667 TZS
Doors	320 000 TZS	1 600 000 TZS	30 400 000 TZS
Electrician	50 083 TZS	250 417 TZS	4 757 917 TZS
Paint	40 000 TZS	200 000 TZS	3 800 000 TZS
Other costs	29 867 TZS	149 333 TZS	2 837 333 TZS
Total cost (TZS)	2 312 617 TZS	11 563 083 TZS	219 698 583 TZS
Total cost (SEK)	9 717 SEK	48 584 SEK	923 103 SEK
Labour	613 333 TZS	3 066 667 TZS	58 266 667 TZS
Savings without labour cost	21%		

The head teacher at the schools estimated that it would cost about 3 000 000 TZS to construct the kind of facilities with six toilets they have today (Augustsson & Nylund, 2020). This would correspond to 47 500 000 TZS for 95 toilet units, which only is 22 % of the estimated cost for this project. Nevertheless, it is unclear which costs are included in the head teacher's estimation and that solution would not be a safe sanitary solution, even if the number of toilets were to be satisfactory.

5 Discussion

The most suitable solution for the Bulyaheke and Mandela primary schools is the Fossa Alterna, out of the two solutions evaluated in this study. It is fairly easy to construct, use and maintain and it is likely to be accepted by the local population. It reduces the risk of sanitary diseases well, and if functioning and maintained correctly it minimises manual handling of un-sanitised excreta. When the pits are elevated like in this design it reduces the risk of contaminating the groundwater and simplifies the emptying of the pits. The composted effluents and urine can be used as valuable fertiliser and soil conditioner for the school crops, possibly increasing the yield and accordingly the income from selling the crops. It may also reduce eventual costs that currently are spent on fertiliser and reduce the use of chemical fertiliser which is good for the environment. However, using human excreta as fertiliser is not accepted in all cultures and whether that is the situation or not in this case is not known and has to be further investigated. It might also be possible to educate the population or show with pilot projects the benefits of recycling excreta as fertiliser, if there is resistance to the concept. Still, in that case the matter should be handled with caution and respect to local culture.

The implementation of new toilet facilities and menstruation rooms together with RWH for handwashing and hygiene purposes enables a more equal school and especially improves the situation for the female students. Girls risk losing a fourth of their education after they have come of puberty if they have no possibilities to manage their personal hygiene during menstruation. The recommendation is to make the menstruation rooms clean, safe and colourful to promote user friendliness and reduce some of the taboos that are common around menstrual issues. These taboos are big problems, even in countries like Sweden, since they often are based on myths about menstruation, sex and the female reproductive system. Even a little reduction of these taboos or correction of the myths are a step in the right direction.

Even though there are many sanitary problems in the area of Bulyaheke, there are multiple benefits of choosing the schools as a first implementation site. The intention is for this to work as a pilot project to show that it is a viable solution and inspire the population to construct similar facilities of their own. The school already have active education on sanitation and hygiene and by constructing the new facilities the sanitary situation for over 4000 children is improved at once with relatively simple means. The students hopefully adopt the new facilities quick and easy and will tell their families and friends about the benefits of this solution. The intention is that this in turn will induce the families to build their own toilets for household use or upgrade and adjust the ones they have. The design and drawings in this report are adapted to 45 students using each toilet unit only during the school hours but the design can easily be adjusted for household use. One toilet unit is estimated to be sufficient for all-time use by maximum 18 grownups. If there are fewer people in the household the easiest adjustment is to reduce the height, and thereby the volume, of the pits.

Similar expectations can be applied to the implementation of the RWH at the schools. RWH together with SODIS treatment is an eminent method for household use and the SODIS project in 2019 had a lot of positive prospects but might need another nudge. If RWH is practised continuously at the schools, it might remind and inspire the families of the students to use the method at their homes. RWH at the schools may also reduce water, mud and puddles on the schoolyard that otherwise might be a source of infection for sanitary diseases. However, the foremost purpose of RWH is still to enable water for handwashing which is one of the most important precautions to reduce the spread of sanitary diseases and pathogens.

There are some local prerequisites that would make the biodigester solution a viable option. If the school would have a kitchen and serving meals to the students, then the biogas would come to efficient use as cooking fuel. This would be beneficial both in terms of the reduced particles in the kitchen compared to firewood fuel which would make a better health environment for the people working in the kitchen but also it would save time and money compared to the expensive and/or time-consuming process of gathering firewood. Serving the students food is also likely to increase school attendance and reduce risk of malnutrition (Ministry of Education Science and Technology, 2016). Furthermore, kitchen scraps could be added to the biodigester which would help increase the C/N ratio and reduce solid waste management. If there were partially stabled farm animals at the schools or nearby their manure could be added to the biodigester which would increase the biogas yield and even the efficiency since most farm animal manure have more favourable composition for methane production than human faeces.

Nevertheless, a biodigester solution would require a lot of local commitment and dedication since it is a more technically advanced solution with higher maintenance than the Fossa Alterna solution. It might even require a full-time employment of someone with sufficient knowledge to be in charge of the facility and its proper maintenance and operation.

During this project a lot of questions have arisen about the local prerequisites, both of cultural and social aspects but also of technical nature. Since the study trip in the previous project by Augustsson & Nylund (2020) was cut short due to the Covid-19 pandemic and had other objectives than of this study, the information about local prerequisites is limited. There has been no luck when trying to contact the local organisation FUO, the District Water Engineer or other contacts in the area, this may also be due to Covid-19 or for other reasons. Even without the Covid-19 pandemic or communication problems there is neither budget nor equipment to do a hydrogeological investigation or other on-site testing that would be the normal procedure when doing any sanitation project in Sweden. Therefore, there are some assumptions and simplifications made during this project. However, the assumptions are made according to best practise principles and based on other similar projects, information from EWB-SWE and other aid organisations.

It is important to keep in mind that qualitative evaluation and design of this kind are always more or less biased due to personal experiences and limitations in literature research. If another person would have done this study the outcome may have been different. The limitations in known prerequisites and the large cultural differences between Sweden and Tanzania makes this project especially delicate to this matter. It is important to be as objective and transparent as possible when choosing criteria and making assumptions.

To reduce the bias of this study the criteria and background information have been chosen from several different literature sources and discussed with people with other knowledge and experiences than the author. To be more objective it would have been good to do a user survey amongst the students and other inhabitants of Bulyaheke. This would also include the local perspective and create local involvement which is important to create a sense of ownership and responsibility toward the facilities. This was however not possible in this study due to Covid-19 and the absence of response from FUO.

Another way to be more objective is by trial and error, building several different toilet solutions at the schools and do meticulous observations and measurements of the user habits and other technical parameters. However, this would be time consuming, expensive and require advanced technical equipment and local engagement, which puts it outside the scope of this thesis. Nevertheless, it might be a good project for EWB-SWE to implement as a pilot project and reference for prospective projects.

When researching literature, a lot of previous projects similar to this one was found, both within EWB-SWE and other organisations. However, I have had a hard time finding evaluations of implemented projects and when speaking to other members of EWB-SWE it seems to be a general problem. The evaluations that were found had mainly positive feedback, which would not coincide with reality since there is mostly room for improvements, and there is no comprehensive structure of evaluation methodology. These aspects make them unreliable as sources. The limits in evaluations and follow ups of previous projects makes it hard to assess if these projects were successful or not, or if something could have been improved and therefore considered when doing this project.

6 Conclusions

Based on the known prerequisites and the assumptions made the recommended sanitary solution for the Bulyaheke and Mandela primary schools is the Fossa Alterna double pit urine diverting dry toilet system together with RWH for handwashing facilities. The suggestion is to build 19 toilet blocks with five toilets each and place the blocks in clusters around the schools for closer access from different places in the schools. The pits are advised to be constructed of cement covered bricks and to be mainly elevated from the ground level to reduce the risk of groundwater contamination and to simplify the emptying of the pits. If the groundwater table is found to be low, the pits can be completely or partially buried in the ground, leaving a safety distance of minimum 1.5 m between the bottom of the pits and the groundwater level.

The recommendation is to use one of the two pits in each toilet for six months, and then seal and switch used pit, leaving the faeces to decompose for minimum six months. The resting pit will then be emptied before the pits are switched again. The decomposed excreta will be used as fertiliser for the school crops or disposed safely. In this way the pits will be used alternately until the end of the lifetime of the constructions. There is no need for moving or building new toilets, unless there is a need for increased capacity. The urine pits will be used similarly, with a minimum storage time of one month, and then it will be used as fertiliser for fodder or processed edible crops. If the urine is stored for at least six months, it could be used for all crops. If there is no need or possibility for the use of urine fertiliser it could be infiltrated to the ground, preferably after one month storage and with sufficient safety distance to any water sources.

However, the contact with the FUO needs to be re-established and the assumptions about prerequisites made in this project needs to be controlled and eventual adjustment to the design made thereafter. It is recommended to present the design to the FUO, teachers and students at the schools to let them give their point of view before moving on to implementation. The design and cost estimation also need to be adapted to the locally available material, which currently is unknown.

The recommendation is to use this thesis, and the two previous ones, as basis for implementation and when applying for funding. They could also be used to show the importance of improving the sanitary situation in Bulyaheke and how this can be done. Furthermore it is suggested that the evaluation and design in this project is used as support for future similar projects by EWB-SWE or other stakeholders. If the project is implemented, it is recommended to do extensive evaluation and follow up to create reliable references for future projects.

7 References

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8 Appendices

Calculations for Fossa Alterna design

Table A 1. Input parameters for Fossa Alterna

Parameter	Notation	Value
Number of students at the schools	a	4100
Number of students per toilet	b	45
Number of toilets	c	95
Number of toilets per block	d	5
Number of toilet block	e	19
Faeces production, wet weight	m_f	250 g/cap/day
Factor for part in school	f_f	0.5
Faeces density	ρ_f	1.06 kg/L
Faeces retention time	t_f	0.5 years
Urine production	v_u	1.4 L/cap/day
Factor for part in school	f_u	0.3
Urine retention time	t_u	1 month

To calculate the size of the faeces pits, the volume produced during the retention time was first calculated, eventual volume decrease over time is assumed to be equal the volume of other additives.

$$Volume\ one\ faeces\ pit = \frac{m_f * f_f * b * t_f}{\rho_f} = 0.97\ [m^3]$$

The height of the pit is chosen to 1 m with a safety distance to the floor of 0.2 m, effective height is therefore 0.8 m. The width is fixed to 0.85 m due to the design of the stall. The backside of the pit is shaped like a right-angled triangle with a base of 0.4 m and height 0.8 m, hence the length of the pit becomes:

$$L = \frac{0.97\ [m^3] - \frac{0.4\ [m] * 0.8\ [m] * 0.85\ [m]}{2}}{0.85\ [m] * 0.8\ [m]} + 0.4\ [m] = 1.72\ [m]$$

The urine pits are designed as two alternating pits for each block of five toilets, hence the needed volume for one pit is:

$$Volume\ one\ urine\ pit = v_u * f_u * b * d * t_u = 2.87\ [m^3]$$

Similarly like the faeces pit the height is chosen to 1 m with a safety distance to the floor of 0.2 m, effective height is therefore 0.8 m. The width is fixed to 4.7 m due to the design of the construction. The length of the pit then becomes:

$$L = \frac{2.87\ [m^3]}{4.7\ [m] * 0.8\ [m]} = 0.76\ [m]$$

The surface area required for the Fossa Alterna solutions is for one toilet block is 29.74 m^2 which is measured from the drawings, however the stairs, menstruation rooms and handwashing facilities are not included in this area. The total required surface area is calculated as:

$$Total\ surface\ area = e * area\ of\ one\ block = 19 * 29.74\ [m^2] = 565\ [m^2]$$

Similarly the roof area is measured on the drawings to 24.15 m^2 for one toilet block, hence the total roof area is calculated as:

$$Total\ roof\ area = e * roof\ area\ one\ block = 19 * 24.15\ [m^2] = 459\ [m^2]$$

Calculations for biodigester design

The parameters in Table A 1 are used for the design of the biodigester as well, but the additional parameters in Table A 2 are also needed.

Table A 2. Input parameters for the biodigester.

Parameter	Notation	Value
Daily total influent	i	2.11 m^3/day
Faeces VS production	VS_f	110 g/cap/day (Meynell, 1976)
VS loading rate	VS_L	3.2 kg/m^3/day (Meynell, 1976)
Retention time secondary treatment	t_s	0.5 years
Water addition per kg faeces	w	3 l/kg

The total needed volume for the digester tanks, the retention time and needed water can be calculated as:

$$Digester\ volume = \frac{VS_F * b * c}{VS_L} = 147\ [m^3]$$

$$Retention\ time = \frac{Digester\ volume}{i} = 69.7\ [days]$$

$$Required\ water = w * b * c * m_f * f_f = 1603\ [l/day]$$

The surface area for the digester tanks, given that the tanks are 2 m high and a surface addition of 10 % is estimated for wall thickness, can be calculated as:

$$Surface\ area\ digester\ tanks = 110\% * \frac{147\ [m^3]}{2\ [m]} = 80.8\ [m^2]$$

The total needed volume for the secondary treatment tanks can be calculated as:

$$Secondary\ treatment\ volume = i * t_s = 385\ [m^3]$$

The surface area for the secondary treatment tanks, given that the tanks are 2 m high and a surface addition of 10 % is estimated for wall thickness, can be calculated as:

$$Surface\ area\ secondary\ treatment = 110\% * \frac{385\ [m^3]}{2\ [m]} = 211.7\ [m^2]$$

The total needed volume for the urine tanks can be calculated as:

$$Urine\ tanks\ volume = 2 * v_u * f_u * b * c * t_u = 109.2\ [m^3]$$

The surface area for the urine tanks, given that the tanks are 0.8 m high so they can be placed under the stalls, and a surface addition of 10 % is estimated for wall thickness, can be calculated as:

$$Surface\ area\ urine\ tanks = 110\% * \frac{109.2\ [m^3]}{0.8\ [m]} = 150.2\ [m^2]$$

The 95 toilet stalls are designed with width 1.2 m and length 1 m, hence the total surface area for all stalls is:

$$Surface\ area\ toilet\ stalls = 95 * 1.2\ [m] * 1\ [m] = 114\ [m^2]$$

The total area for the biodigester solution, excluding menstruation rooms, mixing and expansion chambers, gas storage and handwashing facilities, can then be calculated as

$$Total\ surface\ area = 80.8 + 211.7 + 150.2 + 114 = 556.7\ [m^2]$$

Calculations for RWH

Table A 3. Parameters for the RWH calculations.

Parameter	School buildings	Toilet buildings
Roof area, school buildings	1500 m^2	460 m^2
Yearly average precipitation	1120 mm	
Yearly RWH	1680 m^3	515.2 m^3
Daily RWH	4.6 m^3	1.4 m^3
Total daily RWH	6 m^3	
Tank volume, one month RWH	180 m^3	

$$Yearly\ RWH = roof\ area * yearly\ precipitation$$

$$Daily\ RWH = \frac{yearly\ RWH}{365}$$

The RWH tanks are dimensioned after the average RWH of one month:

$$Tank\ volume = daily\ RWH * 1\ month$$

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