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Identification of sanitation solutions for the Cochabamba region, Bolivia

A comparison between peri-urban and rural areas

Bachelor Thesis in Civil Engineering

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Preface

This report is a bachelor thesis under the division of Water and Environment Technology at Chalmers University of Technology in Gothenburg, Sweden. The study is a part of a continuous project in Cochabamba, Bolivia.

Firstly, we would like to thank Martina Nilsson, Laila Olsson and Abraham Nina Arteaga, who gave their permission to use their photographs in our report. Moreover, we want to thank Caterina Dalla Torre, at the Swiss Federal Institute of Aquatic Science and Technology, who allowed us to use their illustrations of sanitation components.

We have received a lot of advice, support and guidance throughout the work process of this report. Therefore, we would like to thank the people that have shared their time and knowledge with us; Kat Wasberg at Water for People, who provided us with information about the projects in Cochabamba and Tiraque. Also, Claudia Cossio Grageda, PhD student at the division of Water and Environment Technology at Chalmers University of Technology, who with her valuable experience and knowledge of the study areas has helped us define realistic scenarios and was helpful throughout the work process.

Finally, we want to thank our supervisor Sebastien Rauch, associate professor at Chalmers University of Technology, who has followed and helped us through the work of this report.
His support and knowledge has been invaluable in the compilation of this thesis.

Gothenburg, May 2015

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Sammandrag

Varje dag dör 1400 barn under fem års ålder på grund av brist på rent vatten och undermåliga sanitetsförhållanden. Denna studie fokuserar på Bolivia, ett av Sydamerikas fattigaste länder, där 50 procent av befolkningen saknar tillgång till säkra sanitetslösningar.

Cochabamba är den tredje största staden i Bolivia, en stad med hög urbaniseringsgrad och informella bosättningar i utkanterna av staden som följd. I studien jämförs de rådande förutsättningarna för sanitet i de peri-urbana områdena med motsvarande förutsättningar i Tiraque, som är en stad på landsbygden i samma region. Kandidatuppsatsens syfte är att, genom en jämförelse av sex tänkbara alternativ, föreslå den mest lämpliga sanitetslösningen för respektive studieområde. Jämförelsen genomförs med en multikriterieanalys.

Efter genomförd multikriterieanalys är det föreslagna alternativet en urin-separerande torrtoalett. Lösningen är resurseffektiv, miljövänlig och passande för en föränderlig stadsdel. En av de identifierade utmaningarna med implementationen av torrtoaletten i Cochabamba är att få den att bli socialt accepterad av invånarna. Studien presenterar en implementationsstrategi som utgörs av informationskampanjer och nyetablering av sanitetsrelaterade företag. Tiraque är ett stabilt landsbygdssamhälle med möjligheter att installera en permanent och hållbar sanitetslösning. Den föreslagna lösningen är en cisternfri vattentoalett kopplad till en slamavskiljande septiktank med ett avloppssystem fritt från fast material. Vattenreningen sker genom konstruerade våtmarker medan reducering och hygienisering av slam genomförs med planterade torkbäddar. Identifierade svårigheter, som kan uppstå i Tiraque, är att uppförandet och installationen av det nya systemet kräver kompetens som kan vara svår att få tag på. En utmaning är också säkerställandet av att underhållsrutiner efterföljs. Implementationsstrategin för Tiraque bygger på ett samarbete mellan kommunen och de lokala vattenkooperativen som finns i staden. Implementationsstrategierna för båda studieområdena är beroende av finansiellt stöd och kompetens från en icke-statlig organisation.

Nyckelord: Sanitet, Vatten, Bolivia, Hälsa, Öppen defekation, Multikriterieanalys, Torrtoalett, Avlopp

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Abstract

Every day, 1400 children under the age of five die due to lack of clean water and insufficient sanitation. This study focuses on Bolivia, one of the poorest countries in South America, where 50 per cent of the population lacks access to improved sanitation.

The third largest city in Bolivia is Cochabamba, a city with high urbanisation rate and informal settlements in the peri-urban parts of town. In this study, the prevailing prerequisites for sanitation solutions are compared between a peri-urban area of Cochabamba and a rural town in the same region, Tiraque. The aim of this bachelor thesis is to suggest the most applicable sanitation solution for each of these study areas. A comparison of six plausible alternatives is conducted with a Multi Criteria Analysis.

The result indicates that the urine-diverting dry toilet, UDDT, is the most applicable solution for peri-urban Cochabamba. The solution is resource efficient, environmental friendly and is suitable for a changing townscape. A great challenge identified in Cochabamba is to make the UDDT socially accepted by the inhabitants. The study suggests an implementation strategy based on information campaigns and the introduction of businesses related to sanitation. The rural town Tiraque is a stable community with possibilities to install a permanent and sustainable solution. The suggested solution is a pour flush toilet with a solids-free sewer system, constructed wetlands and planted drying beds. Identified difficulties in Tiraque are the competence requirements to ensure correct construction and maintenance compliance of the system. The implementation strategy for Tiraque is based on collaboration between the municipality and the local water cooperatives. In both areas, the implementation strategies are dependent on financial and competence support from a non-governmental organisation.

Key words: Sanitation, Water, Open defecation, Bolivia, Health, Multi Criteria Analysis, Dry toilet, Sewer

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1. Introduction

Every day, 1400 children under age five die because of the lack of clean water, proper toilets and knowledge about hygiene (UNICEF, 2014), despite the fact that access to clean water is a human right. In Bolivia, one of the poorest countries in South America, more than 50% of the population lacks access to improved sanitation (UNICEF & WHO, 2014) and many people practise open defecation. This causes large spread of pathogens, which leads to disease transmission among the population.

In Bolivia, there is a problem with uneven distribution of governmental funding and not all inhabitants can benefit from municipal services (S. Rauch, personal communication, February 2, 2015). The city of Cochabamba is the third largest city in Bolivia with approximately 630 000 citizens (Jonsson, 2015) in 14 different districts. The peri-urban areas are not planned by the municipality and therefore not recognised in the budget. In addition to this, the areas are growing very fast without municipal control and building legislation. The inhabitants are poor and seldom pay taxes (S. Rauch, personal communication, February 2, 2015). This makes it difficult to get resources to improve the water and sanitation systems in peri-urban and rural areas.

Smaller towns have to deal with fewer residents but often lack the organisation and funding required to develop and maintain infrastructures. One example of a small rural town is Tiraque, located in the Tiraque province in the department of Cochabamba. It is a rural area with agriculture as main employment. Tiraque town has 1900 inhabitants and a majority has access to improved sanitation but the wastewater treatment plant is old and poorly maintained.

1.1 Aims

The aim of this bachelor thesis is to conduct a comparison between six plausible alternatives for improved sanitation and suggest the most applicable sanitation solution for the peri-urban Cochabamba and the rural town Tiraque. The comparison is taking social, economical and ecological aspects of sustainability into consideration. Furthermore, the thesis aims to evaluate the suggested sanitation solutions and propose implementation strategies that can be applied in the peri-urban and rural contexts.

1.2 Relevance of the Project

Providing access to safe drinking water and functioning sanitation for everyone is one of the greatest engineering challenges of our time. Today, more than 900 million people worldwide still lack access to an improved drinking water source and 2.6 billion do not have access to improved sanitation (UNICEF & WHO, 2014).

All around the world, the urbanisation rate is high and half of the world's population already lives in cities, where the vast majority have an unsatisfactory level of infrastructure and capacity to address wastewater management in a sustainable and efficient manner (Steiner & Tibajuika, 2010). Insufficient wastewater infrastructure leads to polluted water bodies and spreading of severe diarrheal diseases. Due to this, contaminated water from non-functioning wastewater management is a factor for increased poverty, through costs of health care and lost labour productivity. The predicted population growth and climate changes is going to aggravate the sanitary situation even more and if no action is taken, many millions of people will continue to fall ill in diseases with fatal outcomes. In addition to this, there will be great losses in the biodiversity and ecosystem resilience, eroding the prosperity and attempts towards a more sustainable future (Corocan *et al.*, 2010).

The project investigates solutions for sanitation and aims at addressing the sanitation challenge by looking at options for rural and peri-urban areas. The purpose of the systematic comparison between different sanitation solutions is to help identifying the needs and prerequisites in each area. Since the study regards known environmental issues such as eutrophication, urbanisation, population growth and contamination, the project also addresses to sustainable development.

1.3 Delimitations

In order to restrict the scope of the project, a number of limitations have been stated throughout the work process. This, to make the extent of the report manageable within the given timeframe of a bachelor thesis. Due to the limited amount of time, the group has not been able to travel to the actual area of the study, which has restricted the project to a literature study without empirical data. It has therefore been difficult to acquire information about for example inhabitants' opinions and costs in their authentic context.

The study is confined to waste generated from humans and does not include industrial wastewater with pollution like chemicals and persistent substances.

The comparison was conducted between six plausible combinations of sanitation components commonly used in a developing country context. There are probably many other solutions that could have been compared, but it was concluded that six is an adequate number, due to the given timeframe and in order to limit the extent of the project.

1.4 Problem Description

The city of Cochabamba has grown rapidly the last years and many neighbourhoods in the southern peri-urban parts of town are not under municipal management and lack access to water and basic sanitation. People in this area are generally working in the informal sector, have limited resources and live under scanty circumstances. There is a variety of ways that people solve their sanitation situation, but in general the hygiene status is low and many people get sick and die in water related diseases every year. Water is a scarce commodity in this area, which adds to the challenges of good sanitation.

The education level of the inhabitants in the area is generally low and lack of comprehension for the importance of hygiene and disease spreading impedes development. Many people are status conscious and may choose a solution that is the most popular, even if it is not the most suitable or effective choice. The peri-urban area of Cochabamba is densely populated and therefore the land usage is another issue to address. Municipal legislation enable the people living in the area to obtain tenancy over their land after a certain amount of years, which complicates the land owning question further. The circumstances in the peri-urban part of Cochabamba are put in contrast to the prevailing conditions of Tiraque, a rural town in the same region. In Tiraque, the municipality has more influence over the infrastructure development. This has resulted in a higher level of sanitation where most people in the town centre have functioning toilets. However, their wastewater treatment plant is under-dimensioned and aged, which lead to other environmental hazards. The differences in needs and conditions between these contexts are important to identify in order to achieve a deeper understanding for the magnitude of the problem and start to approaching ideas for sustainable solutions.

The concept will consist of several components that are composed into different holistic solutions to treat human waste from source to recipient. Important factors that are considered in the study are resource consumption, the usage phase, hygiene qualities and long-term environmental aspects.

1.5 Method

The project is a literature study with elements of personal communication with key persons that have been visiting the study area. Information and facts about the lifestyle and livelihoods in the study areas have mainly been received from the mentor of this study, Sebastien Rauch, associate professor, and Claudia Cossio Grageda, a Bolivian PhD student both practicing at the institution of Water Environmental Technology, Chalmers University of Technology.

Six chosen sanitation solutions are compared in a Multi Criteria Analysis, MCA. The MCA is a systematic comparison tool developed to enable decision-making in complex problems when many parameters are considered (Mendoza & Macoun *et al.*, 1999). Each parameter is given a score to emphasise its importance or impact. The outcome of the MCA is a logical and well-structured result that presents a solution that received the highest score, and therefore is most suitable for the prevailing conditions.

The study takes both social and technical issues into account in order to determine not only the best technical solution but also the most likely to have a successful implementation. The study areas are influenced by political instability and poverty, which may lead to difficulties obtaining scientific and impartial information about Bolivia.

2. Description of the Study Area

The study is based on the current situation in Bolivia, and focuses on a peri-urban area in the city of Cochabamba and a rural town in the Tiraque province in the department of Cochabamba. To better understand the given circumstances where the study is conducted, a description of the study area is given below.

2.1 The Plurinational State of Bolivia

Bolivia is a country located in the middle west of South America, see figure 1. The state has about 10.7 million inhabitants (World Bank [2], 2013) and among the population there are many different ethnicities represented, hence the name *The Plurinational State of Bolivia* (Jakobsson & von Konow, 2015). The majority of the indigenous population consists of Quechua and Aymara and in addition to these there are at least 35 other ethnicities among the population (Nilsson & Olsson, 2014).

Figure 1: Map of South America, Bolivia marked in green (CIA World Factbook, 2015) Public Domain

The topography in Bolivia varies a lot in the different parts of the country. The west part is dominated by the high *Andes* and in the east part, called *Oriente,* there is lowland (Behrens, 2015). The third variant of topography is the tableland in southwest called *Altiplano*, where Lake Titicaca is located. The different altitudes make the climate very varying and in Altiplano the climate is characterised by cold winds and very little precipitation, whereas in the lowlands of the Oriente it is often hot and humid (Behrens, 2015).

The poverty in Bolivia is widespread and about half of the population lives in moderate poverty which means that the family's income is barely enough to afford basic needs like food, clothes, health care and shelter (World Bank [3], 2015). Bolivia is a country that is very conscious about class society therefore the effects of living in poverty are extra palpable (Galván, 2011). The differences in living standards between urban and rural areas are considerable and statistics indicate a pattern of social dejection that affects the rural population, especially the indigenous people (Galván, 2011).

In the three largest cities of Bolivia, La Paz, Santa Cruz and Cochabamba (see figure 2) the population increases rapidly which has resulted in a lot of people living in informal settlements where the municipalities lack the capacity to meet the increasing needs of infrastructure and service systems (Nilsson & Olsson 2014).

Figure 2: Bolivia map (CIA World Factbook, 2015) Public Domain

Bolivia is one of Latin America's most politically unstable states with major problems with corruption (Business Anti-corruption Portal, 2011). Since independence in 1825 the country has had 16 different constitutions and about 200 extra-constitutional changes of government (Berg, 2013). Most of these have been implemented through bloody military coups but since 1982, Bolivia’s government is democratically elected (Berg, 2013).

Evo Morales has been the president of Bolivia since 2005. He is the first indigenous president and has a big support from various groups in the society. He won the presidential election for the third time in a row in October 2014 and his electoral support has continuously increased during his time in power (Carlos, 2014). The main reason of the major support is that Morales has many groups of allies, ranging from coca farmers to leaders of social movements, with vested interests in the governing politics (Petras, 2013). The Morales government has a strict fiscal policy, and an example of this is that the pay raises in the public sector are very modest. In combination of increased costs of living, this is a struggle for many of the citizens. The government has not been accommodating to strikes and other sorts of rebel uprisings arranged by public sector unions. The fiscal policy has low taxes and a stable currency, which has been beneficial for business people and bankers, both national and from other countries (Petras, 2013).

2.2 Cochabamba

The city of Cochabamba is the third largest in Bolivia and is continuously expanding. It is located at an altitude of 2 550 metres above sea level and according to Jonsson (2015) the city has around 630 000 inhabitants, nevertheless, due to a rapidly growing population and Bolivian settlement legislation it is hard to determine the exact number of inhabitants (Jonsson, 2015). The city of Cochabamba is the capital of the Cochabamba region, one of nine regional departments in Bolivia (Klein, 2003). The Cochabamba department consists of 16 provinces divided into 45 municipalities (Nilsson & Olsson, 2014)

The area surrounding Cochabamba city has a temperate climate and is called *The Valley of Eternal Spring* (Boliviabella, 2015). The average precipitation is approximately 450 millimetres per year and mostly concentrated to the rain season in the summer months of January and February, as seen in diagram 1. The rest of the year there is arid climate, which leads to considerable water deficit (Danilo, 1993). There is one river in Cochabamba, Rio Rocha, but this river is severely contaminated and cannot serve as water source (Nilsson & Olsson, 2014)

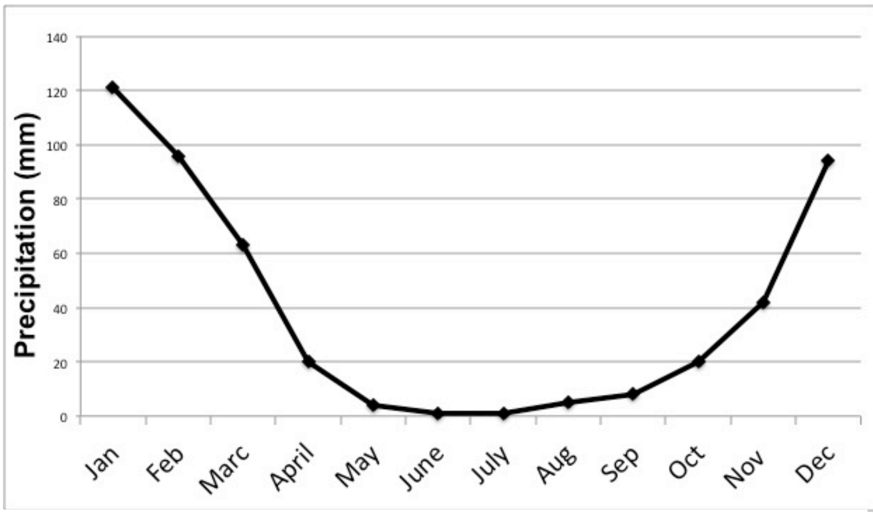

Diagram 1: Average precipitation in Cochabamba according to Cordesius and Hedström (2009)

The city of Cochabamba is a segregated town and the socio-economic differences between the different parts of town are substantial. According to Rauch (personal communication, February 2, 2015) the majority, 90 per cent, of the municipal budget was allocated to the three most central and well functioning districts whereas the informal settlements in the outskirts of town received nearly nothing. The southern parts of Cochabamba city is worst affected by the fast urban sprawl and in the peri-urban neighbourhoods many people live in areas that are not acknowledged by the municipality.

In June 2012 a new law, *La Ley 247,* was accepted to help and protect the citizens of informal settlements and give them tenure when they have been living on the land for at least five years. However, this law does not comply when the informal settlements are located in areas that are considered hazardous to live in (Nilsson & Olsson, 2014). Many people that live in informal settlements also work in the informal sector and do not pay taxes, which adds to the financial problems of funding a functioning infrastructure in the areas (Nilsson & Olsson, 2014).

Cochabamba has a problematic history with its water distribution. In 1998, the International Monetary Fund suggested that Bolivia should privatise their water supplies, since their analysis was that the government did not have the funding or knowledge to care for the water distribution properly. One year later, the Bolivian parliament approves *The Drinking Water and Sanitation Law* that enabled privatisation of the drinking water and sewage disposal (Sadiq, 2002). The new law led to discontent among the people and led to consequences the authorities could not have foreseen. Rumours and speculations said that the privatisation would make the residents pay higher prices for the water services, which would strike hardest at the poorest in society and people started to demonstrate on the streets. What started as a peaceful protest against the decision soon turned into a violent riot against the authorities. After months of uprisings and instability, the municipality decided to withdraw the decision and the distribution of water were once again governed by SEMAPA (Achtenberg, 2013).

2.3 Tiraque

Tiraque is a province in the department of Cochabamba, founded in the 17th century. A majority of the economic activity in Tiraque province is associated with agriculture (Cossio Grageda, 2014) and the most produced crops are potatoes, corn, onions, beans, wheat, fruit and coca leaves (Gobierno Autonomo Municipal de Tiraque [2], 2015). Tiraque is situated 3 200 metres above sea level, with an area of 688 square kilometres (Cossio Grageda, 2014).

Figure 3: View of the town of Tiraque during rain season (Photo by Abraham Nina Arteaga) Published with permission

The province has a population of approximately 33.000 inhabitants. There are several rivers in the Tiraque province, for example Rio Tiraque, Rio Toralapa and Rio Linky Mayu and the water levels in the rivers varies with the season. According to studies by Cossio Grageda (2014) the water has a high concentration of faecal coliform bacteria and parasitic eggs, which make the water bodies unfit sources for drinking water or irrigation.

The capital of Tiraque province is Tiraque town and in the city centre, other economic activities such as shops, restaurants, tailors and carpenters can be found. Every Friday a market is arranged in Tiraque town where people from neighbouring villages and other counties come to sell their crops and livestock. The town of Tiraque has approximately 1900 inhabitants but on during the market, the amount of people multiplies (Cossio Grageda, 2014).

2.4 Current Sanitation Situation in the Study Areas

Bolivia is the least developed country in South America when it comes to sanitation. According to the Joint Monitoring Program Report by UNICEF and the World Health Organization (2014), 46 per cent of the population has access to improved sanitation services in the urban areas. In sparsely populated areas outside of the cities, some numbers go down to two per cent (Water For People [1], 2015). The water distribution and sanitation challenges in Bolivia have caused the need for people to cooperate and the citizens are commonly organised in water cooperatives in their neighbourhoods (S. Rauch, personal communication, May 7, 2015).

The shortage of financial and material resources might be the most obvious reasons to the current water sanitation problems, but the issue is complex and there are many factors to take in account. For example, in the older generations, men and women are used to defecating outside and the women wear long skirts called polleras, which gives them the ability to defecate discretely (Fogelberg & Sparkman, 2011). Unfortunately these customs are not applicable in urban areas with a dense population and when practising open defecation, faecal separation from food and water cannot be ensured. This leads to the spreading of pathogens that causes diseases as cholera, typhoid, hepatitis, polio, diarrhoea and worm-infestation (UN, 2015). Another troubling factor is that people in general does not have a handwashing routine, thus they do not realise the importance of hygiene in order to prevent disease transmission. In rural areas many people live with animals very close to the house, which also can cause health issues because of the risk of contact with animal faeces in combination with a lack of hygienic habits (C. Cossio Grageda, personal communication, February 16, 2015).

The practise of open defecation in the world is closely associated with other social issues. For example, if the need for defecation occurs at after nightfall could be dangerous due to for example the presence of snakes, insects and violators (Nilsson & Olsson, 2014). Moreover, no access to toilets forces many teenage girls to leave school when they start menstruating and due to the lack of privacy there is a high risk that women become victims of sexual violence (UN, 2015).

2.4.1 Water Distribution and Sanitation in Cochabamba

Water in the Cochabamba valley is a scarce commodity. SEMAPA, Servicio Municipal de Agua Potable, is the municipal water system but their capacity is not enough to provide services for all parts of the rapidly growing city (SEMAPA, 2015). In the peri-urban Cochabamba there is no municipal piping network to transport water. Instead, the inhabitants buy their water from trucks (Marston, 2014). This is problematic since the price is not regulated and the drivers of the water trucks can therefore set prices arbitrary, which makes this water more expensive than the water provided by SEMAPA and the quality of it does vary. As an attempt to improve the water safety, some trucks nowadays have a registration number. This gives the consumers a possibility to find the drivers and report complaints. Many people store their water in used metal barrels, illustrated in figure 4, which is problematic since these are not always properly cleaned from their former use as oil or chemical barrels.

Figure 4: Water barrel used in peri-urban Cochabamba (Nilsson & Olsson, 2014) Published with permission

As an example to illustrate the injustice and differences between northern and southern areas, see figure 5, the average water consumption in the southern peri-urban areas is two cubic metres per month and costs ten per cent of the family's monthly income. In comparison, the average water consumption in the northern, more privileged, areas is 30 cubic metres per month and costs two per cent of the family income. Furthermore, the differences in sanitation accessibility affect the health of the inhabitants and the average life expectancy differs from 54 years in the south to 78 years in the north (S. Rauch, personal communication, February 2, 2015).

Figure 5: Pictures of the northern and central part of Cochabamba on the left and southern peri-urban parts of Cochabamba to the right (Nilsson & Olsson, 2014) Published with permission

As earlier mentioned, the informal settlements in the southern parts of Cochabamba are not connected to the municipal water system and the people here do not obtain the same services as the inhabitants in the northern parts of town (Marston, 2014). Some neighbourhoods attempt to establish their own water distribution through water cooperatives, but far from all projects succeed (C. Cossio Grageda, personal communication, February 16, 2015). Nevertheless, the incumbent water and sewage systems in north are old, poorly maintained and water leakages are common. The existing wastewater treatment plant is undersized and not all wastewater is sanitised before let out in the Rio Rocha. Many wealthy families in the privileged districts have water-flushed toilets but the wastewater treatment is incomplete. The toilets are considered to be a status symbol, so people who can afford it prefer this solution before other, less water consuming, alternatives. The inhabitants in general show a lack of concern in environmental issues and are not willing to pay the price for improved sanitation and wastewater treatment. This behavioural can be explained by poor knowledge about the long-term consequences of poorly sanitised wastewater and the restrained economic situation in the country (S. Rauch, personal communication, February 2, 2015).

2.4.2 Water Distribution and Sanitation in Tiraque

The city of Tiraque is connected to a sewer network and has three water treatment plants for wastewater. In the town of Tiraque a majority of the people have access to improved sanitation such as flush toilets (C. Cossio Grageda, personal communication, February 16, 2015).

The water treatment plants are not functioning satisfactorily as a result of poor maintenance, which has lead to that sewage has reached nearby water bodies without complete sanitation. Once a week the system load increases due to the Friday market and the outlet of contaminated effluent is yet more extensive than regular days. According to Cossio Grageda (2014), the environmental consequences of this outlet are varying over the year. During the dry season the low and slow moving flows in the rivers cause negative impacts when pollutants from untreated wastewater sediment and percolate into the soil. This problem is not as severe during the rain season since high flows make the pollutants diluted over a greater amount of water and area.

The rural areas surrounding Tiraque town have not reached a satisfactory level of sanitation. According to statistics by Water For People ([2], 2013), about 40 per cent of the people in the area practise open defecation. The municipal board of Tiraque cooperates with non-governmental instances such as Water For People, WFP, and World Vision PDA to improve the province's water and sanitation status (Gobierno Autonomo Municipal de Tiraque [1], 2015).

3. Common Pollutants from Insufficient Sanitation

Human waste contains several types of water pollutants like *suspended solids*, *pathogens, nutrients*, and *organic material* and in some extent *heavy metals* (Henze & Comeau, 2008). A brief presentation of these five common impurities and their environmental impact is given below.

3.1 Suspended Solids

Suspended solids are visible physical particles and could be anything drifting or floating in the water for example sand, silt, plankton and algae (Kemker, 2014). These solids affect the effluent negatively in different aspects depending on the particle size, for example, coarser fractions could clog rivers or channels as they sediment (World Bank [4], 2015). The amount of finer solids that not settle can be denoted as the level of turbidity in the water. Very turbid effluent causes for example inhibited photosynthesis by blocking sunlight, which results in death of underwater vegetation. This in turn leads to less food for aquatic life and less oxygen available in the water. Other pollutants such as pathogens, nutrients and metals may also attach to suspended particles and therefore turbidity is a good overall indicator of the water quality (Kemker, 2014).

3.2 Pathogens

Blackwater is the technical term for wastewater containing human excrement and urine, flush water, anal cleansing water and dry cleansing materials (Tilley *et al*., 2014). The rest product from treatment of blackwater is faecal sludge. Blackwater is the primary source to incidence of disease-causing microorganisms, pathogens, in water bodies such as lakes and groundwater (Nathanson, 2015). Pathogens, in this context, are different types of bacteria, viruses and parasites that occur in human faeces (Ottosson, 2004). These pathogens are mainly causing various kinds of diarrheal diseases, which every year lead to the death of more than two million humans around the world (Tomilola *et al*., 2014).

3.3 Nutrients

Human waste contains phosphates and nitrates. If untreated wastewater reaches water bodies, these nutrients can cause excessive growth of algae and organic matter in the recipients (World Bank [2], 2015). This phenomenon is known as eutrophication and is a well-known environmental issue. Species that crave a lot of fertilisers will be privileged and grow fast, whereas other plants and animals will not obtain enough space and eventually suffocate. This excessive growth causes oxygen deficit in the water and can also affect the pH-levels that determine which species that can survive in the environment. These effects of eutrophication cause disruption in the biodiversity and disturb the natural ecosystems (Corcoran *et al*., 2010).

3.4 Organic Substances

Organic materials are molecules that are based on carbon (Barnstable County, 2015) and refer in this case to faecal matter. The biodegradable organics in the wastewater serve as food for microorganisms present in the water, but to thrive and multiply, these organisms also need oxygen. If untreated blackwater that contains bacteria and organic material reach a water body, the bacteria will consume a lot of oxygen from the water, oxygen that is also crucial for the life support of fish, other animals and organisms in the recipient (World Bank [4], 2015). Therefore, effluent with large amounts of organic material in recipients may lead to oxygen depleted lake- and seabeds (Kemira, 2015).

3.5 Heavy Metals

Cadmium, Lead, Mercury, Arsenic and Zink are all examples of heavy metals, which are a common type of contamination in industrial wastewater. The sources are mainly street runoffs and industrial activities like metal finishing, textile dyes and leakages from dumping sites (Ramböll, 2013). Heavy metals are relevant to mention since these pollutants can be found in faeces and urine (Jönsson *et al.*, 2005), since heavy metals exist in the surrounding environment and can be absorbed by the human body (Skolvision, 2015). For example Cadmium and Mercury can, in larger quantities, cause acute, chronic toxicity and diseases like cancer when accumulated in the body (Ramböll, 2013). These metals are also detrimental to aquatic life (Kemker, 2014).

Metals from the wastewater accumulate in the sludge (Alonso Alvarez *et al*., 2002) and this is one of the reasons that the use of sludge as fertiliser for human food production is disputed. Phosphorus is a finite resource (Conradin, 2015), but the positive environmental aspects of nutrient recycling collide with the risk of heavy metals, eutrophication and the spreading of pathogens and other pollutants.

4. Multi Criteria Analysis

The comparison of solutions is conducted with a Multi Criteria Analysis, MCA, which is, as earlier mentioned, a tool for complex decision-making. Firstly, the prevailing conditions in the study area are presented, thereafter the criteria that are considered in the study are explained. The criteria are disaggregated into four topics with corresponding parameters. The numbers of parameters for each topic are related to their significance in the study and motivations for these priorities are presented in chapter 4.2.1.

In the chapter *Valuation in Relation to the Study Areas*, each parameter is given a weighting score to emphasise the importance or impact of the parameter in the different areas. High score indicates positive features whereas a low score is negative. Ultimately, the solution with the highest total score is considered to be the most appropriate. Small differences in the final result could implicate that more than one solution is suitable. The ranking is formulated with a bottom-up approach as described by Mendoza and Macoun (1999).

4.1 Study Areas

As earlier mentioned, the study focuses on two neighbourhoods, one located in the peri-urban part of Cochabamba and the other in the rural town of Tiraque. The conditions presented in chapter 2 are in this section simplified and summarised with estimated numbers derived from prevailing data, in order to facilitate the MCA and enable an efficient scoring and comparison.

4.1.1 Peri-urban Area of Cochabamba

The study area is a district located in the peri-urban area in the southern part of Cochabamba. The district is home to 340 families and a majority of the inhabitants have a low income and work in the informal sector and 75 per cent of the households lack access to basic sanitation service. The municipality of Cochabamba does not acknowledge the neighbourhood as a part of the city and SEMAPA does not provide any water or sewage service. Moreover, the practise of open defecation is common. Many people have moved to the neighbourhood from rural areas where the consequences of open defecation are not as severe as in the peri-urban area with denser population. People continue with these customs because of habit, lack of money or knowledge to establish an improved sanitation facility. The driving forces for people to improve their sanitation situation vary, but some examples are status awareness, to avoid the shame and nighttime dangers, ranging from snakes and scorpions to robbers and rapists. However, the awareness of the negative environmental consequences is low and the connection between good hygiene and good health is not general knowledge.

4.1.2 Tiraque

The town of Tiraque is home to 350 families and common occupations are carpenters, masons, construction workers, shop and restaurant owners. The vast majority of the inhabitants have flush toilets and the municipality of Tiraque is in charge of the sewage system. The toilets are flushed with water buckets and are connected to a water pipe system that leads to a wastewater treatment plant. The plant is old, insufficiently maintained and under dimensioned, which causes environmental problems due to outlet of poorly sanitised water in recipients.

4.2 Criteria

To analyse the situation and confirm which solution that is most appropriate to implement in each of the study areas, a number of criteria has been evaluated. The criteria are divided into four topics with various numbers of corresponding parameters. The topics are *Resources, Usage, Hygiene* and *Long-term Environmental Aspects*, see figure 6.

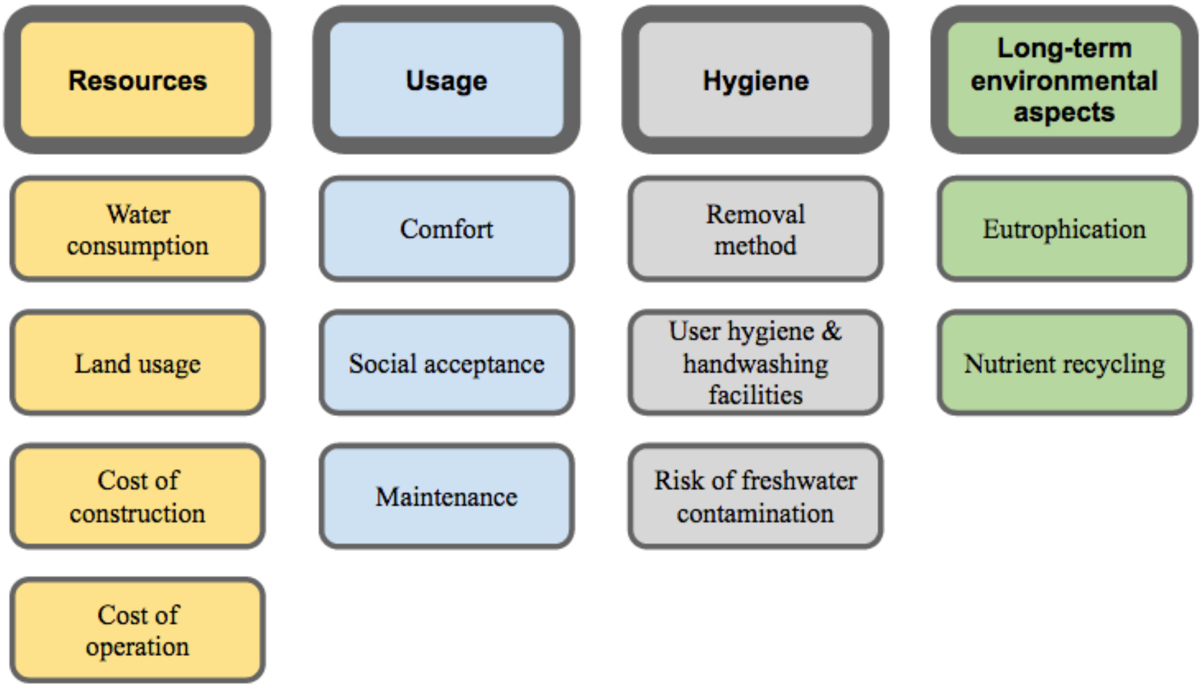

Figure 6: Topics and corresponding parameters that are evaluated in the MCA

4.2.1 Priority of Topics

The importance of the different topics is correlated to the number of the underlying parameters. The reasoning for this priority is explained below.

The topic *Resources* has four parameters since the limited resources are the restraining factor in order to realise the suggested solution. Therefore, this topic is the most important.

The topics *Usage* and *Hygiene* are both given three parameters. To achieve a successful implementation it is of utter importance that the inhabitants are willing to use the solution and in order to improve the health in the area it is also essential that the solution is hygienic.

It may seem unsustainable that the topic *Long-term Environmental Aspects* only has two parameters, but the motivation for this priority is that the most urgent problem in the study areas is, as already mentioned, to improve the health and hygiene situation for the inhabitants. It is also important to address the ecological sustainability to protect the surrounding flora and fauna and reverse negative anthropogenic environmental impacts, but in this study these problems are less prioritised.

4.2.2 Resources

The different improved sanitation solutions have different demands and use of resources, which makes this topic important to consider. Moreover, the concept of sustainable development includes an efficient and restricted usage of resources (Gleick, 1998). In the study areas, many resources are limited and therefore a higher score is given the solutions that require fewer resources.

Water consumption is an important factor since the water shortage in both study areas is severe. An efficient use of water is economically beneficial because there will be a smaller quantity of water to handle, transport and manage in a treatment process (US EPA [7], 2015).

Depending on the location, the amount of accessible land varies. The parameter *land usage* indicates how space consuming the solution is, which is important since there might be land use conflicts in the areas.

Cost of construction considers expenses during the building phase. This parameter includes for example material, work hours, machines, consultation and prospecting.

Cost of operation regards costs for routine and unforeseen maintenance that the owner has to pay for. This parameter includes for example the charges of mechanical disposal, refill products and eventual repair expenses.

4.2.3 Usage

In order to achieve a successful implementation of the solution, the user friendliness and the willingness among the inhabitants to use the new facility is important. User experience is a subjective matter but scored points try to represent a general opinion correlated to the stated parameters.

The *comfort* is relevant since it is important that the inhabitants are willing to use the toilet. If the toilet for example generates a bad smell, attracts many flies or exposes the user to visual discomfort, the likelihood of successful usage is reduced.

Another issue that is important to consider is *social acceptance* that regards the user's opinions about the toilet facility (Warner, 2004). If the toilet has a bad reputation in society, is radically different to what the users are accustomed to or the technology forces the owner to handle the rest products during emptying or maintenance, people may be reluctant to buy and use the product.

The *maintenance* of the system is also important since a complicated solution demands more work and involvement from its owner. If the owner needs education or special equipment to do the maintenance, it might be difficult to ensure the routine compliance.

4.2.4 Hygiene

Regardless of which sanitation solution that is used, hygiene is a crucial factor for the health situation in the study areas. Possibilities to ensure good hygiene decrease the risk for spreading of pathogens.

Removal of waste can be executed either manually by the owner or mechanically by trucks. *Removal method* is a parameter where a high number indicates a secure removal with low risk of human contact with faeces and therefore a low risk of pathogen spreading. A low number indicates a high risk for disease transmission. If the solution has a sewer system the removal and risk of contact with faeces is minimal.

Another relevant factor is that the user understands the importance of hand washing in order to reduce spreading of germs and viruses. The parameter *user hygiene and hand washing facilities* refers to the user's risk of contact with faeces and the possibilities for the users to wash their hands after defecating. When the solution is water-based, the faeces are flushed away directly after defecation. Moreover, access to water increases the possibilities of hand washing compared to if a dry solution is used. Hand washing at a dry toilet, without water, makes alcoholic sanitisers necessary. This might be expensive and less obtainable, especially in rural areas. Additionally, studies show that alcoholic gel is not as efficient as water and soap (Pickering *et al.*, 2010), therefore a water-based solution is valued higher than a dry solution.

The parameter *risk of freshwater contamination* considers the risk of polluting the groundwater and freshwater sources with pathogens and other contaminants such as particles, organic compounds and nitrates (Lenntech [2], 2015). Contaminated groundwater is a health hazard if the contamination takes place in close connection to a source used for drinking water (US EPA [4], 2015) and is also negative for surrounding flora and fauna since it can affect the biodiversity and ecosystems due to pH-changes in the soil (USGS, 2015). In the study areas water is a limited resource and watercourses can be sensitive for pollutants and climate changes. If a freshwater source is contaminated, diseases can spread rapidly and cause epidemics with fatal outcomes (Blackburn *et al.*, 2004). A solution with a low risk of freshwater contamination therefore scores a high point in the MCA.

4.2.5 Long-term Environmental Aspects

The long-term environmental aspects regard phenomenon that are induced by human activities with effects that may not be directly visual but could generate major consequences for the surrounding environment.

The parameter *eutrophication* is based on the risk of over-fertilisation in the surrounding area. If sewage is let out in the nature without treatment, nutrients like phosphorus and nitrogen in the water may cause eutrophication in nearby watercourses (Chislock *et al.*, 2013), which is further explained in chapter 3.1.2. Immense blooming of algae and plants in fresh water sources is problematic in many aspects. The water quality is deteriorated by pollution from for example blue-green algae that spread poisonous cyanobacteria, and the quantity is decreased by sedimentation and overgrowth of plants (Lenntech [1], 2015). Conclusively, a solution that contributes to eutrophication scores low in the MCA since fresh water is a scarce commodity.

Sewage and sludge contain nutrients that could be reused as fertilisers in agricultural activities (European Commission, 2015). *Nutrient recycling* is beneficial from an environmental point of view since phosphorus is an exhaustible resource. The parameter evaluates the solution's efficacy of nutrient reuse in agriculture.

The problem in general for these long-term environmental aspects is that the delay in the cause-effect chain can make it hard for the user to realise the consequences of their actions. According to Rauch (personal communication, February 2, 2015) people in general show a lack of concern about environmental issues when the consequences do not directly impact their own lives.

4.3 Valuation in Relation to the Study Areas

The study areas have different needs and conditions and therefore, each parameter is given a value between one and three, corresponding to its importance. Since the location qualities differ, the parameters have different values in Cochabamba and Tiraque, and the parameter weight is decided in consideration of the geographical and social circumstances in each area.

The weighting of parameters is necessary in order to distinguish the qualities that are restricting for a successful implementation in each solution and area of application. The weighting is a helpful tool in the complex challenge of finding the most applicable sanitation solution.

4.3.1 Given Parameter Weights for Resources

The parameter *water consumption* is given the parameter weight 3 in Cochabamba and 2 in Tiraque. In both areas the climate is dry and water is a scarce commodity, but in Tiraque there are more possibilities to harvest water because of mountain springs and nearby rivers.

Land usage is given the parameter weight 3 in Cochabamba and 1 in Tiraque. Cochabamba is densely populated with many informal settlements and an unregulated urban sprawl. This contributes to the restricted availability to unexploited land plots, which makes land use efficiency of utter importance. In Tiraque town the land is also restricted, but since the town is under municipal governance and surrounded by farmland, there are more possibilities of land-intensive infrastructure development, which makes the land use efficiency less important than in Cochabamba.

Cost of construction is allocated the parameter weight 3 in both Cochabamba and Tiraque since monetary funding is crucial in order to build, implement and make the new system available for the inhabitants. It is irrelevant that the solution is efficient and environmentally friendly if the citizens in the study area cannot afford to build it. The investment capital can be funded in many ways, by the municipality, non-governmental organisations or private micro-finances. However, the start capital is equally crucial in both areas and is therefore given the same score.

Cost of operation is given the parameter weight 3 in both Cochabamba and Tiraque. In order to ensure regular maintenance and uphold the functionality of the system, it is vital that the cost of operation is at an affordable level. If the price for proper maintenance is high there is a substantial risk that the routine compliance is not prioritised, which may contribute to a non-functional system with low hygiene quality that leads the situation back to status quo.

4.3.2 Given Parameter Weights for Usage

The parameter weight for *comfort* is 2 in both Cochabamba and Tiraque. The user must find the new solution comfortable in order to adapt to the new system and leave old habits. For example, if there is a lot of odours and flies the user may prefer to go outside. It is redundant to build a toilet that is unpopular and not used.

Social acceptance is rated with 3 in both Cochabamba and Tiraque. It is vital that the solution is accepted and that the inhabitants actually use the sanitation system. The toilet is a status factor in the distinctive class society that prevails in Bolivia and this factor is of equally importance in the both study areas.

Maintenance is allocated the parameter weight 1 in both Cochabamba and Tiraque. The maintenance focuses on the workload for the owner to ensure the hygiene and function of the toilet. The maintenance scores the lowest rating since it is less important in comparison to the other parameters.

4.3.3 Given Parameter Weights for Hygiene

Removal method is rated with 1 in both Cochabamba and Tiraque. The low ranking is motivated by the fact that the removal is performed relatively seldom. Moreover, there are only one or two persons executing the emptying, and hence are at risk of contact with human faeces. The removal is performed equally regardless of location, therefore there is no difference in the rating between the two study areas.

User hygiene and handwashing facilities is given the highest score, 3, in both Cochabamba and Tiraque. This parameter is equally important irrespective of location and evaluates the fundamental problem of pathogen spreading, which each year causes diseases and death of many people in countries with malfunctioning sanitation. The risk of human contact with faeces is dependent on the user interactive step of the solution and in order to prevent disease spreading, handwashing is an important factor. If the faeces are removed immediately after performed defecation, the risk of contact is minimised.

Risk of freshwater contamination is rated with the parameter weight 3 in both Cochabamba and Tiraque. If a fresh water source, used for drinking water, is contaminated it can lead to severe consequences regardless of location. The access to fresh water is fundamental and in both study areas there is a water deficit, hence the high score.

4.3.4 Given Parameter Weights for Long-term Environmental Aspects

Eutrophication is given the parameter weight 1 in Cochabamba and 2 in Tiraque. Over-fertilised water bodies that dry out can cause negative consequences for humans in a long time perspective, since it may eliminate important freshwater sources. However, the problem is not as acute as some of the other concerns. In the peri-urban area the uttermost factor is to remedy the urgent sanitation situation, which makes the risk of eutrophication a secondary issue. In Tiraque, where the situation is relatively stable, the risk of eutrophication is more relevant to consider.

Nutrient recycling is allocated the parameter weight 1 in Cochabamba and 3 in Tiraque. The main employment in Tiraque region is agriculture and fertilisers are essential for a productive farming. It is beneficial for the inhabitants in Tiraque if the solution provides an opportunity to obtain nutrient rich fertilisers with high quality. In Cochabamba, the agricultural activity is lower than in Tiraque and the fertilisers are not as important for the livelihoods of people. Nevertheless, the produced fertilisers in Cochabamba can be sold and utilised elsewhere.

5. Technical Description of Sanitation Solutions

This chapter discloses the technical units that are included in the proposed sanitation solutions. The different parts are divided into two segments, where chapter 5.2 associates to dry solutions whereas chapter 5.3 describes the components included in the wet solutions. Dry systems have no water demand, whereas wet solutions require water and further wastewater treatment.

5.1 Terminology

In order to facilitate further reading, an explanation of commonly used terms is described. The explanations of the technical units are retrieved from *Compendium of sanitation systems and technologies* (2014) by the aquatic research institute EAWAG, Switzerland.

Anal cleansing water: Water used for cleaning after defecation.

Dry cleansing materials: Any material used for cleaning after defecation or urination, but usually referring to toilet paper.

Blackwater: Waste water containing faeces, urine, flush water, anal cleansing water and dry cleansing materials.

Flushwater: Water used for flushing and transporting excreta in wet toilet interfaces. It can consist of freshwater, rainwater or stormwater.

Stormwater: Rainwater that does not infiltrate through the soil.

Effluent: Liquids that is separated from sludge or blackwater by a septic tank or other liquid separating systems.

Excreta: Urine and faeces. Excreta do not contain flush water.

Sludge: Excreta mixed with water and to some extent solid materials such as sand or soil.

Pit humus: Nutrient rich hygienically improved material, appropriate to use as fertiliser.

Open defecation: The practise of defecating outdoors without any kind of toilet system.

Superstructure: The part of a building or construction entirely above ground.

5.2 Components for the Dry Sanitation Solutions

This chapter describes the different components that are relevant for the chosen dry solutions, and is subdivided in the categories *usage*, *collection and degradation*, and *application of rest products*. The categories are sectioned in the order they follow in the process of the solution.

5.2.1 Usage phase for Dry Solutions

This section describes the user interactive step of the solutions. Latrines can differ in appearance, comfort and need for maintenance. In this study the chosen latrine alternatives are *unimproved pit latrine*, *dry toilet* and *waterless urine-diverting dry toilet*.

Unimproved Pit Latrine

The most basic and often first step people take from defecating in the open is to build an unimproved pit latrine, since it requires a minimum of resources. This solution has a combined usage and collection step. In primitive cases it can be built made by digging a hole in the ground into which the user directly defecates. Since this kind of pit lack a superstructure, the solution does not provide any privacy for the user and moreover it is not hygienic because of the risk of contact with faeces (C. Cossio Grageda, personal communication, February 16, 2015).

Dry Toilet

Dry toilet is a collective name of toilets that do not require the usage of water. The toilets are often directly connected to underlying pits or different types of chambers where the excreta is stored, see figure 7 (Scott, 2002). Over the pit a concrete platform, called a slab, is constructed. The slab has larger diameter than the pit with a drop hole in the middle where the defecation is performed. A possibility is to also build a pedestal over the drop hole to enable sitting. A circular shaped slab is preferable in order to facilitate the mobility of the slab, since it can be rolled edgeways. A lid that covers the hole is used to prevent insects and other animals such as snakes from entering the pit when the toilet is not used. The lid also contributes to decrease spreading of odours (Reed, 2012).

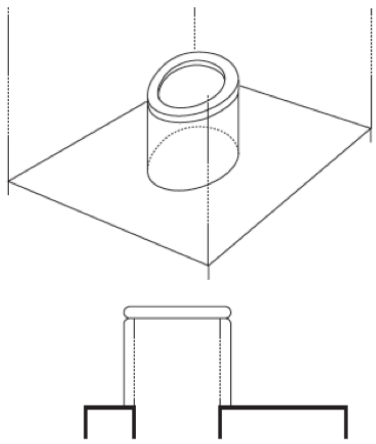

Figure 7: Dry toilet with slab (Tilley et. al, 2014) Published with permission

This system is inexpensive, the construction can be built and repaired with locally bought material and does not require expertise to be executed. If used correctly and cleaned well this is a good way to separate the excrement from human contact, suitable in areas struggling with shortage of water (Reed, 2012). Some negative aspects of a dry toilet are the discomforts for the user, for example odours, the occurrence of flies and other insects around the pit and the fact that a hole leading straight down to the excreta might be visually unpleasant (Tilley *et al.,* 2014).

Waterless Urine-diverting Dry Toilet

A waterless urine-diverting dry toilet is a toilet interface used over a pit or chamber and is constructed to separate urine and faeces. The solution does not require water and enables a different treatment of urine and faeces (Separett, 2011).

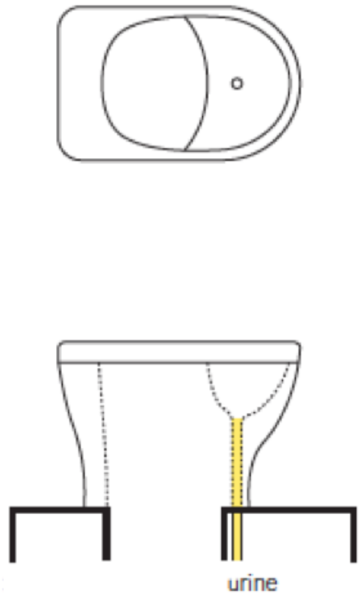

Figure 8: Urine-diverting toilet with slab (Tilley et al., 2014)
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The toilet has one part for the urine in the front that leads into a tank and a larger hole in the back for the faeces, as depicted in figure 8. The two holes have to be separated properly to prevent mixing of the waste. Cleaning with an acid substance is required in order to prevent deposition in the urine tank pipe (Tilley *et al.,* 2014).

This technology demands information for first time users, as the usage differs from most other toilets. For example, the user must wipe with dry cleansing materials to ensure that no water goes into the pit. A waterless urine-diverting dry toilet is more expensive than other dry toilets because of the two-compartment design. It does not attract as much flies as other dry toilet solutions, but it can be a bit difficult to use for people that are new to the system and mismanagement of the system could lead to clogging of the urine pipes. Similar to other dry solutions, this toilet can cause visual discomfort since the faeces are visible in the hole, but compared to other pit solutions this system significantly reduces odours due to the separation of liquids which makes the faeces dry faster (Rieck *et al.,* 2012).

5.2.2 Collection and Degradation

Collection of the excrement varies in the different dry solutions. Crucial parameters that are evaluated in this section are the storage capacity and risk of leakages to surrounding environment. The described collection alternatives for the dry solutions are *Pit latrine*, *Dual pit with Fossa Alterna system*, *Dual pit with Dehydration vaults* and *Urine tanks*.

Pit Latrine

In order to build a single pit system, a depth minimum of three meters and a diameter of at least one meter is required (Tilley *et al.,* 2014). To give the overlying slab a solid foundation and to prevent stormwater from infiltrating, the pit walls are lined with a concrete or brick structure. A schematic sketch of the structure is shown in figure 9. The shape of the pit should preferably be circular, since that makes the pit more stable and prevent surrounding soil and lining structure from collapsing due to surrounding earth pressure. The pit input can be excrement as well as dry cleaning materials and anal cleansing water. As liquids and solids enter the pit, the liquids permeate through the pit floor and walls and the solids are left to decompose. Due to the simplicity of the system, pathogen reduction and organic degradation are not sufficient to make the excreta clean enough to be used as a fertiliser without further treatment.

Instead, it works to keep the excrement away from human contact in order to reduce spreading of diseases (World Bank [1], 2005).

When liquids such as urine, anal cleansing water and rainwater enter the pit, it is important to consider the risk of contaminating the underlying groundwater and nearby watercourses. To prevent this, and ensure that the liquids obtain sufficient filtration before reaching surrounding water bodies, it is recommended to build the pit at least two meters over groundwater level and 30 meter from nearby rivers or lakes. The system is not recommended in areas with heavy rains due to increased risk of overflowing the pit (Graham & Polizzotto, 2013).

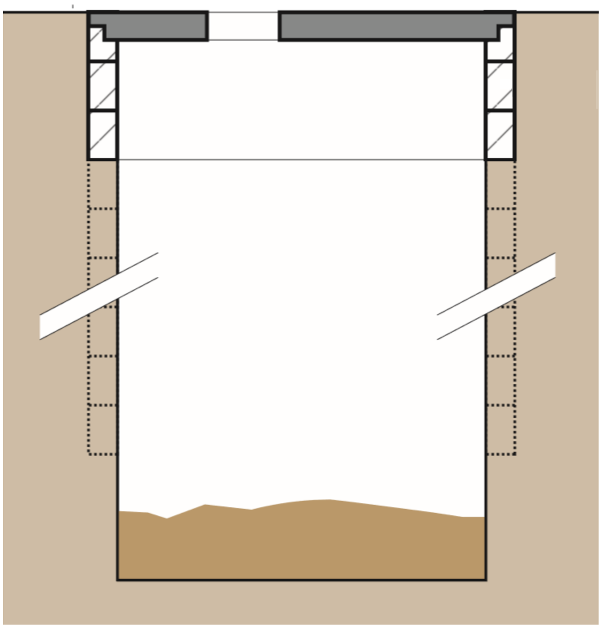


Figure 9: Pit latrine with slab (Tilley et al, 2014) Published with permission

The method relies on the ability to move the construction to a new location when the pit is full, which is space consuming. Therefore it may not be suitable in densely populated areas with potential land use conflicts. This is an inexpensive and simple collection method that can be built without expertise. The system does not produce any soil fertilising products, which is a negative factor in comparison to other dry alternatives. Additionally, health risks associated with contaminated groundwater and flooding during heavy rains make it a not ideal, but a feasible method to use as a first step in areas struggling to evolve from open defecation (Tilley *et al.,* 2014).

Dual pit with Fossa Alterna

Evolving from the single pit system comes the dual pit system as a solution for areas with limited space. The system consists of two pits, which alternate in being active and passive. The active pit is covered with a slab structure and a mobile shelter. The pits are used one at the time, and when one of them is full it is sealed and put to decompose, while the other is put in use. When the second pit is full the first pit has decomposed and is ready to be emptied, as depicted in figure 10. This can be conducted manually since the content of the first pit now is disinfected (Tilley *et al.,* 2014).

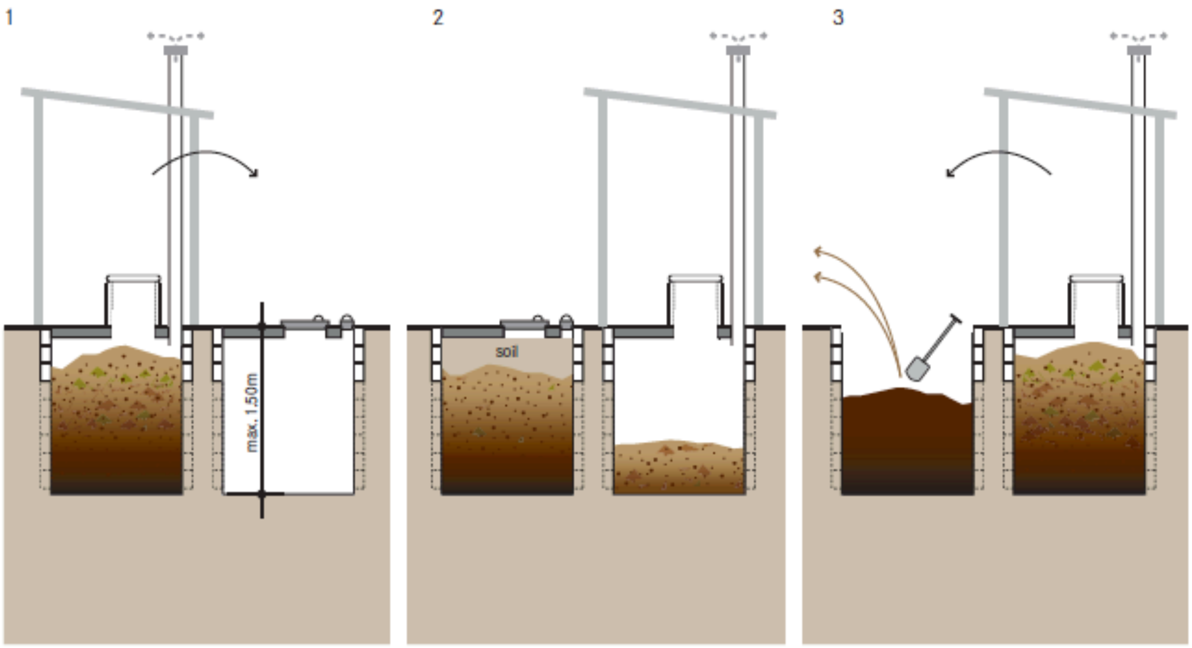


Figure 10: Dual pit Fossa Alterna system (Tilley et al., 2014) Published with permission

To improve the quality of the rest product and decrease the decomposing time, this system uses a method named *Fossa Alterna*. The pit for this method should be shallow, in between 1 to 1.5 m and takes about one year to fill up for six persons. It also requires the user to put cover material as soil, ash and leaves, in the pit after every use. This creates a suitable environment for worms, fungi and bacteria and makes them prosper. These organisms aid the degradation process, which decreases odours and in turn reduces the amount of flies. The composing process takes approximately one year and when the decay is completed, a nutrient-rich humus material, ideal for soil conditioner, is produced. The material can be handled without help of machines, since the decomposing process has reduced the amount of pathogens. The addition of ash, soil and leaves during usage makes the humus material less compact and easier to dig manually. The system is sensitive and it is essential that no garbage is thrown into the pit, since this might disturb the composting process. Because of the shallow depth of the pit, it is possible to build it partially or completely over ground, which reduces the risk of groundwater contamination (Morgan, 2007).

This is a slightly more complicated system than a single pit system, which improves the sanitation standard with a relatively small investment. Because of the dual pits, the system does not require as much space and is therefore suited for densely populated areas. The dry system makes it suitable for areas with limited access to water. It does not demand large economic resources to construct and the user receive high quality soil fertilising humus, which can be used by the owner or sold to farmers. However, manual removal is necessary, which might be regarded as unpleasant and heavy work. Additionally, it is important to assure correct usage, due to the risk that the Fossa Alterna decomposing process is contaminated and disrupted by garbage (Stauffer & Spuhler [1], 2015).

Dual Pit with Dehydration Vaults

Dehydration vaults are waterproof tanks used to decrease the volume of the faeces and process them into a powdery, dry, soil-like material. The vaults are used in a combination with a urine-diverting toilet, since high moisture levels in the waste slow down the dehydration process, see figure 11. While one vault is used, the other one completes the decay (Rieck *et al.*, 2012).

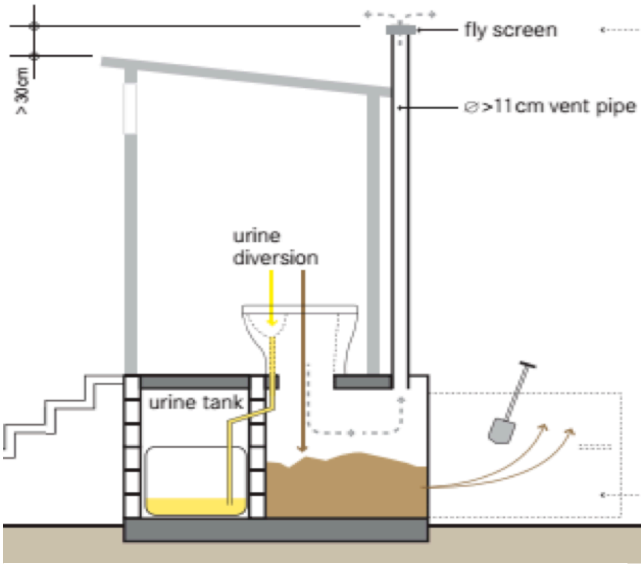


Figure 11: Urine-diverting toilet in combination with dehydrating vaults (Tilley et al., 2014) Published with permission

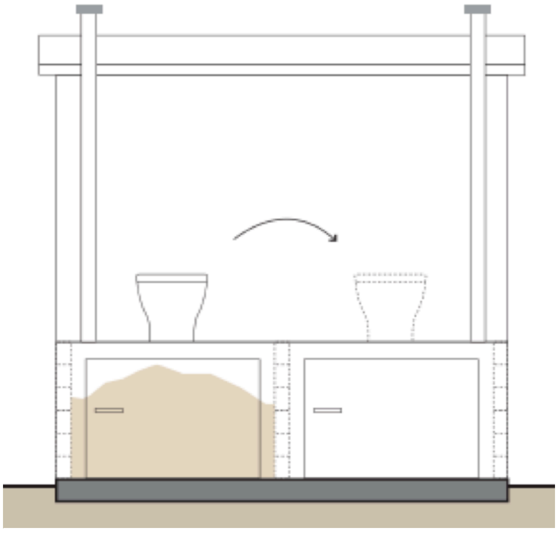


Figure 12: Alternating vaults (Tilley et al., 2014) Published with permission

Under the slab, two dehydration vaults are constructed and similar to the dual pit system described in the previous chapter, the two compartments alternate in being passive and active, illustrated in figure 12. The size of the vaults can vary depending on the number of users. Keeping the faeces dry is essential in this system and to enable this, the vaults are waterproof and have good ventilation. This facilitates the dehydration and decreases the spreading of odours. After defecation, the user puts soil or ashes upon the excrement to speed up the process and keep away the insects. When one vault is full, the pedestal is moved to the other one, giving the passive vault time to complete the dehydration process. The properly dried faeces are disinfected from pathogens and safe to be manually removed and used as soil fertiliser, even though the nutrient level of the humus is not as good as in the Fossa Alterna system, due to lack of urine (Schönning & Stenström, 2004). The decomposing process will go faster than in a regular pit latrine because of the urine diversion. Six months of storage is enough if soil, ash and leaves are continually applied. If not, one year of storage is recommended in a warm climate (Rieck *et al.,* 2012).

Dehydration vaults are preferable for family usage, since many users fill up the vaults too quickly. They are relatively easy and inexpensive to build, but more complicated than pit latrines. The materials can be purchased locally and the building process does not require expertise, although a manual might be needed. Because of the constant use of cover material, there must be an unlimited supply of soil and ashes. Also, this system requires that the users are educated in the importance of keeping fluid away from the dehydration vaults. The water-proof vaults make this system appropriate for areas with high water levels or high risk of flooding (Tilley *et al*., 2014).

Urine Tanks

A urine tank is a removable container used with the urine-diverting toilet, which is connected to the pedestal by a pipe. It is used for storage and transport of urine, see figure 8 (Tilley *et al.,* 2014).

The urine tank, see figure 13, is made of plastic or fiberglass. Metals are not used, because of the high pH level in stored urine, to prevent corrosion. The size of the tank depends on the numbers of users and an average person produces 1-2 litres of urine per day (Bjerneroth Lindström, 2010).

Figure 13: Urine tanks (Tilley et al., 2014) Published with permission

A layer of salts and organic sludge will grow on the bottom of the tank over time. Therefore, it must be easy to access in order to enable cleaning. The pipe also needs some routine maintenance and to facilitate cleaning and removal of clogging objects, a short and wide pipe is recommendable (Rieck *et al.,* 2012). In order to use the urine for fertilisation, it is of utter importance to secure a total separation from anal cleansing water since it may contain excrement pollutants. The risk of disease transmission from stored urine is low and a long-term storage of urine, longer than six months, makes the urine almost completely sanitised. For fertilisation usage, one month of storage is sufficient (Schönning & Stenström, 2004).

5.2.3 Application of Rest Products

Depending on the different processes, the usage of the rest products varies. This part describes what has to be considered during emptying and application of the rest products. The application alternatives that are described are *fill and cover - Arborloo*, *application of stored urine*, *application of dehydrated faeces* and *application of pit humus*.

Fill and Cover - Arborloo

When a pit latrine is full and secure emptying cannot be ensured, the pit can become a risk factor that needs to be covered. A simple solution is to fill it with soil and ash, which makes the old pit an ideal spot for planting trees because of the nutrient rich soil-excrement mixture. This method is called *Arborloo* and in order to improve soil quality it is recommended to put some soil and ash in the pit after every use. The benefits of the Arborloo method are that it is simple and inexpensive but the necessity to dig new holes requires space, which makes it unsuitable for dense areas (Morgan, 2007).

Application of Pit Humus
Pit humus is an earth-like material that is the rest product generated by the Fossa Alterna dry toilet system. It takes one year of storage before the nutrition and pathogen levels of the humus are appropriate to use for soil fertilising (Morgan, 2007). Scientifically, pit humus adds nutrients and organic substances that improve the air and water storage capacity of the fertilised soil, which reduces the need for chemical fertilisers (Rouse *et al.,* 2008). The use of humus in gardens and agriculture makes it possible to grow crops in areas with bad soil quality. Even if it is safe to handle it may be a social acceptance issue for people with no experience of handling excrement (Tilley *et al.,* 2014).

Application of Dehydrated Faeces
The dehydrated faeces from dehydration vaults become a white-beige powder that can be mixed with soil to improve its water holding capacity. Emptying of the vaults is done manually with protective clothes and mask. The dehydrated faeces are not suitable to use as fertilisers and it may be problematic to ensure a sufficiently low level of pathogens (Tilley *et al.,* 2014). The soil enhancing method costs almost nothing but there may be problems with social acceptance since people in general are reluctant to the use of human faeces in association with food production (Rieck *et al.,* 2012).

Application of Stored Urine
Stored urine is a natural and costless source of nutrients for fertilisation. Emptying the urine tank is easy and can be done by the users themselves, but the tanks need to be replaced frequently. It may also be heavy to lift and usually has an unpleasant odour. Urine can also be stored in large quantities and used for irrigation (Tilley *et al*., 2014). If collecting urine in large quantities for commercial usage, six months of storage is recommended to completely sanitise the urine. Urine storage is useful where there is a demand for nutrients in agriculture, but due to the high concentration of nutrients it may also cause over-fertilisation if disposed irresponsibly (Schönning & Stenström, 2004).

5.3 Components for the Wet Sanitation Solutions

This chapter describes the different components that are included in the chosen water-based solution. The chapter is subdivided in the categories; *usage*, *collection and basic treatment*, *emptying of the septic tank and transportation of the sludge, further treatmen*t and *disposal of rest products from wet solutions*. In each category associated components are disclosed.

Similar to chapter 5.2 the components are presented in the order they follow in the process, and the category *disposal* describes how the outcomes from the different solutions are applied and reused.

5.3.1 Usage Phase for Wet Solutions
This section describes the user interactive step of the wet solutions and the selected alternative is the pour flush toilet for all of the wet solutions.

Pour Flush Toilet

A pour flush toilet is a water based toilet solution that operates like a cistern toilet but without a connected container for the flush water. Instead, the user flushes with a bucket, which enables regulation of the water usage after demand (World Bank [5], 2015).

The toilet can be built either with a squatting pan or a pedestal with a superstructure. The pipe beneath the squatting pans is formed like an S with a slight inclination to create a water seal. The seal depth must be at least two centimetres, see figure 14, and is preferable to keep low, in the order to minimise the water required to flush away the faeces (Tilley *et al*., 2014). The quantity of the flushing water must be enough to push the excrement through the S-shape, approximately two to three litres per use depending on the type of waste. The user can cleanse with either water or dry cleansing materials, the later alternative needs to be gathered and not flushed down the toilet to avoid blockages. Using less water may result in more maintenance due to the higher risk of clogging. However, the maintenance is relatively easy because of the construction (Tilley *et al*., 2014). Plastic or ceramic materials are advantageous to use in order to prevent clogs and enable cleaning. Concrete is not an appropriate material because of its rugged surface. Since water already is gathered for this system, it is also recommended to install a water-based handwashing facility with soap in close connection to the toilet to improve the user's hand hygiene (Danielsson, 2015).

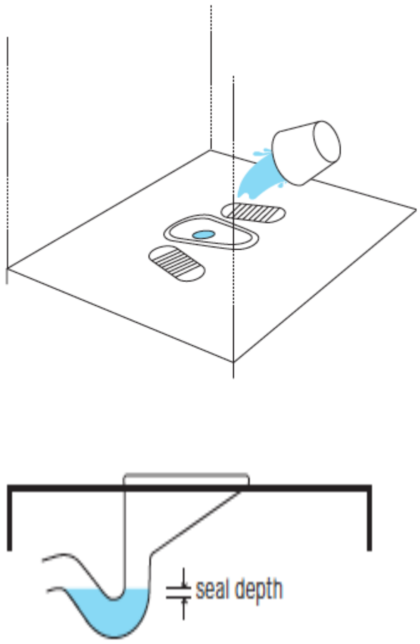


Figure 14: Components of a pour flush toilet (Tilley et al, 2014) Published with permission

The water used for flushing can be collected from different kinds of water sources like nearby watercourses or rainwater. Rainwater collection is a relatively uncomplicated method with low maintenance, and moreover, it is economically beneficial. The gathering of rainwater is usually done by downpipes from roof surfaces and gutters that are connected to a reservoir tank. It is a good water source complement but could be difficult to rely on, due to its dependence of weather conditions (Shende, 2015).

The pour flush toilet can be a locally built and the system is considered to have a high comfort due to a low occurrence of flies and odours, and if operated correctly, there is no visual unpleasantness (World Bank [5], 2015). The slab of a pour flush toilet is easy to mass-produce by local manufacturers because of the availability of materials, which contributes to a low investment cost. The pour flush toilet is socially accepted, user friendly, little maintenance demand, can use different water sources and regulate the water usage according to the necessity. Nevertheless, it is dependent on constant water access and may easily clog, because of restricted water use (Tilley *et al.,* 2014).

5.3.2 Collection and Basic Treatment

Septic tank is the chosen collection-alternative for all wet solutions. In the septic tank, the waste goes through some basic treatment like sedimentation, whereas further treatment is explained in chapter 5.2.4.

Septic Tank

A septic tank is used in combination with a water based toilet facility and is a relatively simple and robust construction. The main function of the system is not to treat the incoming blackwater, but to separate the solids and liquids, therefore it does not significantly reduce pathogens, suspended solids and organic material (NESC, 2015).

The construction of a septic tank contains at least two watertight chambers, depicted in figure 15, usually made of concrete or plastic material (NESC, 2015). In the first chamber, the majority of the heavy particles in the blackwater settle to the bottom while the scum floats on the top. The accumulated particles on the bottom become sludge and start a slow anaerobic decomposition and therefore it is important to not dispose any toxic chemicals into the system. The second chamber prevents sludge and scum to mix with the effluent. The outlet is formed like a T to separate the effluent from the scum (US EPA[1], 2005). Both chambers need to be accessible for emptying the accumulated sludge. The size of a septic tank varies with the amount of users but since it is constructed underground the size is usually not a limiting factor (Spuhler [1], 2015).

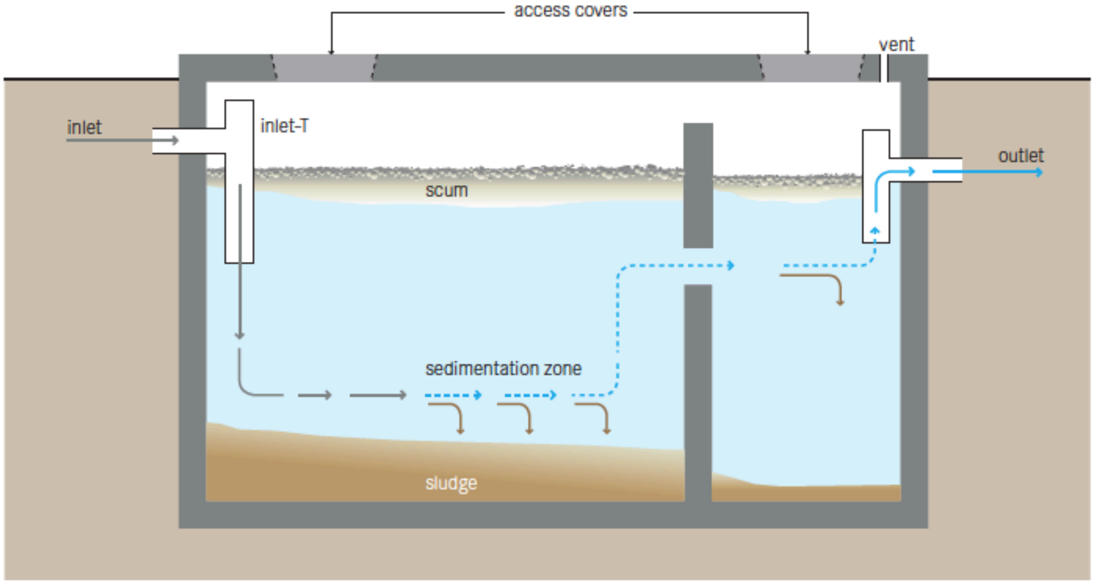


Figure 15: Septic tank (Tilley et al, 2014) Published with permission

Usually the user of a septic tank does not get in contact with the influent and effluent, since the construction is concealed underground. When emptying the tank of sludge, the person emptying has to be careful, since toxic and flammable gas may be released (WTE, 2015). The tank fills up with an interval of approximately three to five years, but if the emptying method is manual it has to be emptied once a year because a hand pump cannot empty the entire tank at once. Furthermore, the tank needs to be regularly checked to ensure that it is watertight (US EPA [1], 2005).

A septic tank has low operating costs and a long lifespan. The construction cost is considerable, since the installation needs expert supervision. The technology does not require any electricity and has a low land usage. Additionally, it is suitable for both single households and neighbourhoods. Nevertheless, compared to dry sanitation components, the septic tank system is considerably more expensive and the reduction of pathogens, solids and organics is low, the effluent needs further treatment (Tilley *et al.,* 2014).

5.3.3 Emptying of Septic Tank and Transportation of Sludge

When the septic tank is full, it is important to empty and dispose the rest products. This can be performed either by *pumping by hand and manual transport* or *motorised emptying and transport.* This part describes the emptying alternatives and handles the description and functionality of a *transfer station*. In order to achieve a sustainable and efficient transport of the effluent a *solids-free sewer* is part of one of the solutions.

Pumping by Hand and Manual Transport

To enable the emptying, a hand pump especially designed for sludge, is applied on the settler. The hand pump works in the same way as a water pump, sucking up sludge by creating vacuum. The bottom of the pipe is lowered in the settler while the person pumping stands on top of the tank. In order for the pump to work properly, the sludge must be fluid (Tilley *et al.*, 2014). If it is solidified, it is necessary for a person to jump into the settling chamber and disengage the sludge manually with shovels and buckets, which is associated with a high risk because of the toxic fumes and exposure to poorly sanitised sludge. To avoid solidification and overflow of the septic tank, it is of utter importance to empty the settler frequently, at least once a year. The sludge is collected in barrels for transportation, and loaded on a trolley. Because of the transportation being performed by lugging a trolley it is important that the septic tank is located close to the disposal site (Stauffer & Spuhler [2], 2015). When pumping by hand, it is crucial that the practitioners use protection in form of masks, gloves, protective suits and boots, which is displayed in figure 16, because of the risk of getting in contact with faeces. Practising pumping by hand on your own can be risky, but with the right equipment, families can do this for themselves (Tilley *et al.,* 2014).

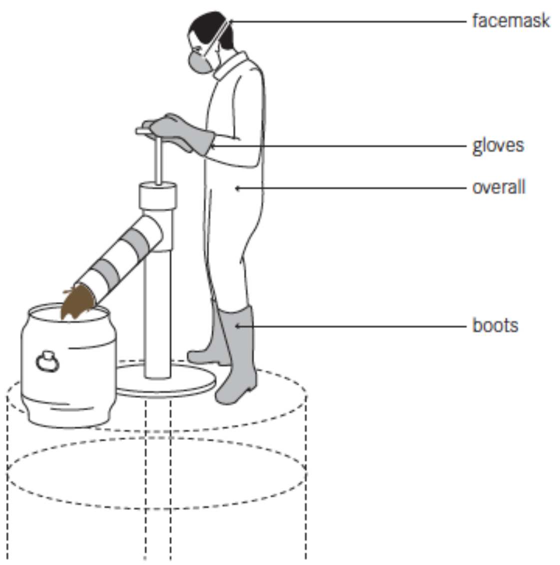


Figure 16: Manual emptying with required safety equipment (Tilley et al., 2014) Published with permission

Motorised Emptying and Transport

A motorised transport means that a vehicle, equipped with a motorised pump and a storage tank, pumps up and transports faecal sludge, blackwater and urine, see figure 17. A person is required to put in the hose and operate the pump, which is connected to a vacuum tank. Professionals perform the motorised emptying and transport, and the hiring cost can be the highest expense of maintenance while operating a septic tank. Because of the different humidity of the sludge it is of importance to operate with a powerful pump and to place the vacuum pump in near distance to the septic tank. Dense sludge in combination with an insufficiently powered pump can result in the need of manual removal with shovels and buckets (Tilley *et al.,* 2014). A problem with motorised emptying and transport is that the trucks may have difficulties accessing septic tanks located in areas with narrow or non-drivable roads. There is also a problem with transport to and from areas located far from plants for further treatment, because of the high costs of labour and fuel (Stauffer & Spuhler [3], 2015).

The use of motorised emptying reduces the need for manual emptying, and thereby also the risk of human interference with faeces. Maintenance of the trucks is another factor that has to be taken in consideration when implementing motorised emptying and transport. Since the trucks not often are manufactured at a nearby location, it might be a problem to find and acquire spare parts and reach a mechanic able to repair broken pumps and trucks (Mikhael *et al*., 2014).

Transfer Station

A transfer station is a fixed permanent underground storage tank where both trucks and private persons can dump sludge, see figure 17. The building of a transfer station requires expertise but apart from the initial expenses, the building material and cost of operation is relatively low (Tilley *et al.,* 2014).

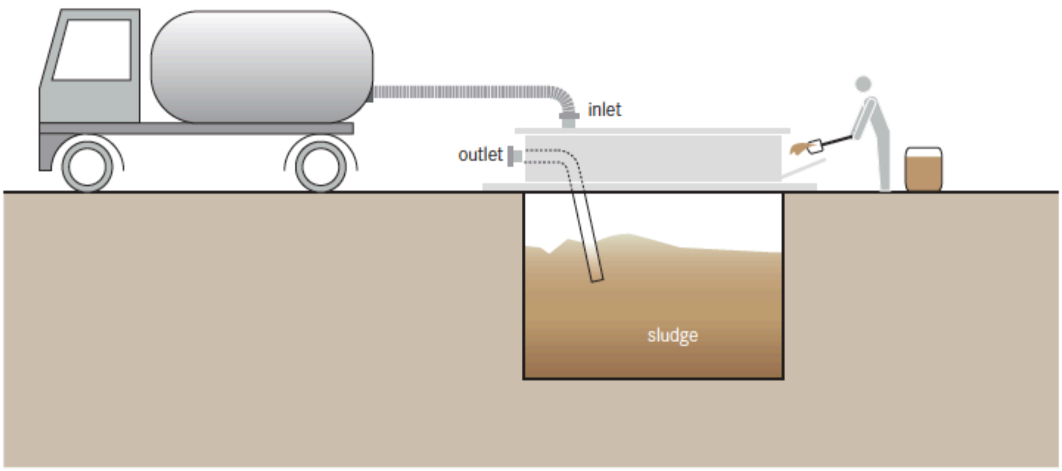


Figure 17: Transfer station with both manual and motorised emptying (Tilley et al., 2014) Published with permission

When the final centralised treatment is located far away, the transportation of sludge from many households can be divided into primary and secondary transportation, with loading and unloading at a transfer station. The presence of a transfer station nearby may reduce the illegal dumping of sludge, which can improve the environment and overall health in the community. This method is simply for storage for a short period of time and the quality of the sludge is the same when unloading and reloading (Mikhael *et al.,* 2014).

Transfer stations are appropriate for dense, urban areas where it is problematic to discharge the faecal sludge. The location of the station is preferably close to the septic tanks that generate the sludge, but must not be built too close to households due to the sanitary risks and unpleasant odours (Tilley *et al.*, 2014).

When determining the appropriate coverage and size of the transfer station the transportation cost must be taken into account. Even though the primary transport may be human transportation with trolleys or wheelbarrows, it is of importance to locate the transfer station in an area where trucks can operate, since smaller trucks also unload at the station. Even if these smaller trucks could drive the entire way to the disposal site, it is economically beneficial for the communities to cooperate and hire a more efficient big truck to drive the second distance from the transfer station to the final destination (US EPA [6], 2014).

Solids-free Sewer

The solids-free sewer uses gravity as the force mechanism. The sewer network only transports solids-free wastewater, since the solid waste is separated and pre-treated in a septic tank (Stauffer & Spuhler [4], 2015). Because there is only effluent going into the sewer there is no minimum flow velocity of the water and fewer inspection points are needed (Robbins & Ligon, 2014).

Compared to a conventional sewer this solids-free system has a flatter gradient and thinner pipes lay in a shallower depth (Tilley *et al.*, 2014). In order to enable purging, the minimum diameter of the solids-free pipes is 75 millimetres. This can be put in comparison to a conventional sewage pipe, which has a standard diameter of 150 millimetres (Faure & Spuhler, 2015). If the downstream end is lower than the upstream end of the sewer, inflective gradients are possible, which makes it easier to follow the topography. It is important to control the efficiency of the septic tank regularly to prevent solids from entering the sewerage. The thin pipes are sensitive and interference of solid waste and dry cleansing materials in the sewer causes clogging. Moreover, the network needs to be connected to a centralised treatment technology where the effluent can be collected for further treatment (Stauffer & Spuhler [4], 2015).

The solids-free sewer network is relatively easy to design, less expensive to build and economical operate compared to a conventional sewer network (Robbins & Ligon, 2014). The system is, however, more costly than other sanitation methods mentioned in this report. A crucial aspect with the sewer network is the possible risk of leakages. Leakages are difficult to prevent and can be hard to find. When leakages occur it may cause disease transmission when the wastewater infiltrates the groundwater. In order to prevent clogging in the sewer network, a periodic flush with larger amount of water is recommended (Tilley *et al.,* 2014). This sewer is appropriate for towns and dense villages, since an outspread network generates too much friction losses to be efficient (Häggström, 2009).

5.3.4 Further Treatment

Since sludge and effluent from the septic tank are not processed, further treatment is needed. The sludge that settles needs to be dehydrated and disinfected before it is possible to use in agriculture. Moreover, the effluent needs treatment in order to reduce suspended solids, biodegradable organics, pathogenic bacteria and nutrients (World Bank [4], 2015).

This section describes two different processes and which factors to consider when operating the systems. *Constructed wetlands* is chosen and described as an optional treatment of effluent and *planted drying beds* for dehydration and disinfection of sludge. In chapter 5.3.5 the component *leach fields,* which combines treatment and disposal, is described.

Constructed Wetlands

In constructed wetlands, natural processes with vegetation, microorganisms and soil works to clean wastewater from pathogens and nutrients (US EPA [2], 2004). An artificial wetland consists of a shallow basin, with varying length depending on demanded volume. It is filled with soil, gravel, sand, water and planted with local swamp vegetation, see figure 18. Pollutants and pathogens are removed and disinfected through sedimentation, adsorption to soil particles and solar UV-radiation. The nutrients are assimilated by the plant tissues and consumed by microorganisms (Cordesius & Hedström, 2009). After passing through the wetland, the treated water is lead into a drainage pipe and can be used for irrigation in agricultural activities (Tilley *et al.,* 2014).

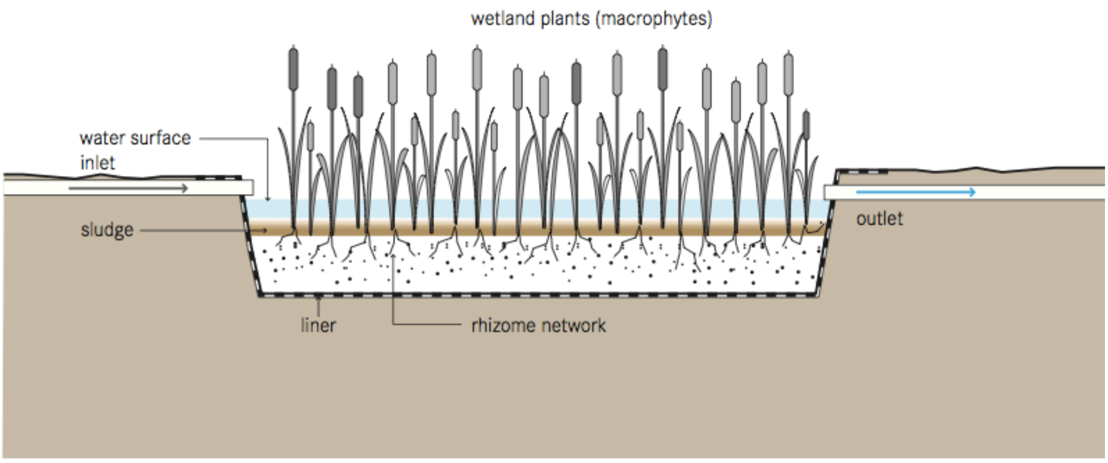


Figure 18: Illustration of constructed wetland (Tilley et al., 2014) Published with permission

Crucial considerations to take into account when constructing wetlands are to construct it on uplands with natural gravitation (Cordesius & Hedström, 2009) and not in near distance to floodplains to prevent damage to natural wetlands. In order to prevent negative environmental effects and disruption of natural habitats, it is important to thoroughly contemplate the location of the constructed wetland. Factors to examine are for example hydrological conditions, the presence of wildlife habitats and the impact of the wetland in the catchment area (US EPA [2], 2004).

This solution is economical to operate since it is mainly based on natural processes. However, it requires expertise to be constructed (Stauffer [2], 2015) and trained staff that carry out regular inspections, maintenance and surveillance (US EPA [2], 2004).

Planted Drying Beds

Sludge extracted from the septic tank is moist or in a liquid state. In order to simplify transport and to generate sludge appropriate for soil fertilisation, the sludge has to be dehydrated. A method to dewater the sludge is by using planted drying beds.

A planted drying bed consists of a concrete frame filled with stones, gravel and sand, into which wetland macrophyte plants are grown. The sludge is put to dry on the sand and gravel surface. As it dries, approximately 50 per cent is evaporated and 45 per cent of the water infiltrates through the layers and canals made by the roots of the plants. To drain the liquids away there are pipes in the bottom of the bed which discharge the leachate away, in some cases for further sanitation. However, the quality of the leachate is dependent of the layers in infiltration bed. If the stratums are efficiently designed the leachate can be used directly for irrigation (Kengne & Tilley, 2014). In order for the sludge to properly dry, the layer must not be more than 20 centimetres thick. By letting the sludge dry for 10 to 15 days the volume decreases with 40 per cent (Spuhler [2], 2015). A negative aspect with the drying beds is that they may attract birds and insects that can become disease vectors when in contact with the sludge in the drying beds (Kengne & Tilley, 2014).

The purpose with the drying beds is, except from dehydrate the sludge, also to improve the overall quality. The nutrient and pathogen level of the treated sludge are indicators of the performance of the drying beds. The efficiency depends on the climate, which plants that are used and for how long the sludge is stored at the drying bed. In general, the storage time is three to five years in order to reach a satisfactory quality (Kengne & Tilley, 2014). The macrophytes contribute to a higher level of treatment compared to a drying bed with no plants, but since the conditions vary, sampling has to be done before the sludge can be used for agricultural activities. The planted drying beds require trained staff to operate and maintain the system (Tilley *et al.,* 2014).

5.3.5 Disposal of Rest Products From Wet Solutions

The separation of sludge and effluent in the septic tank is the first step in the treatment process, which facilitates the disposal and application of the outcomes. This part describes the *leach fields*, *application of sludge* and *irrigation with treated effluent.*

Leach Fields

This system consists of a drainage field with a network of perforated pipes underneath the ground where the effluent from the septic tank can dissipate, see figure 19. The effluent is treated through the infiltration of the soil and is therefore usually not in contact with humans, which contributes to lower the health risks of the system. Leach fields demand expert personnel for construction and a large land area with unsaturated soil.

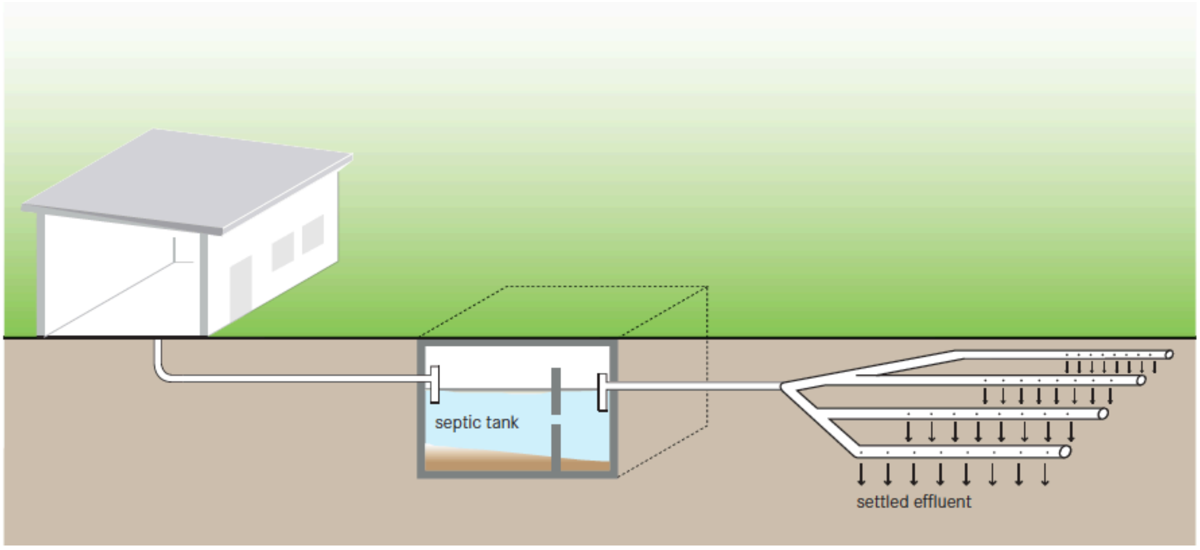


Figure 19: Leach field connected to a septic tank (Tilley et al., 2014) Published with permission

Structures and deep root vegetation above the leach fields are not appropriate since it makes the pipes inaccessible for reparation and can cause settlements in the ground that may damage the network. Due to these restrictions leach fields requires large areas and therefore it is suitable for rural households in towns that are sparsely populated (Gensch & Sacher, 2015).

If the septic tank, that is connected to the leach field, works properly, the field can last for at least 20 years before clogging and wear makes pipe replacement necessary (US EPA[3], 2000). The pipes must be at least 15 centimetres below the surface, to prevent the effluent to flood above ground. In order to achieve a sufficient treatment, the leach field needs to be placed above a layer of permeable soil, at least 1,8 metres thick. Moreover, the layer must be free from coarse fragments and placed above groundwater level (AGWT, 2015). The leach fields must not be placed within a radius of 30 metres from a drinking water source because of the risk of contaminating the water (Tilley *et al.,* 2014).
The system is relatively resource intensive during the construction phase, and the land cannot be used for agriculture and therefore not generate any income, but after installation the system has low operating costs.

Application of Sludge

Large amounts of sludge may be useful for fertilisation, depending on the quality and pre-treatment. A problematic factor is that synthesised pollutants can be found in sludge from large-scale wastewater treatment plants, mostly because of the presence of chemicals in the wastewater from industries (US EPA[5], 1994)

Compared to inorganic fertilisers, sludge has lower nutrient levels but the advantage of releasing the nutrients slowly into the soil. The sludge also increases the water holding capacity, which improves the conditions for agriculture and is beneficial in dry areas. The application of sludge is done by trucks, or if the sludge is in liquid state it can be injected into the soil. All workers are recommended to wear protective clothing (US EPA [5], 1994). The positive effects of application of sludge are the recycling of nutrients and decreased use of inorganic fertilisers (Tilley *et al.,* 2014).

Irrigation with Treated Effluent

Irrigation with recycled wastewater is one way to save fresh water, and thus contribute to sustainable development (NSW, 2004). Instead of dissipate the wastewater into the ground, like in the leach fields, treated effluent from the constructed wetlands can be used for irrigation. It can greatly reduce the use of freshwater in the agriculture and also supply the plants with some nutrition. There are many kinds of irrigation methods, most suitable is drip irrigation, where perforated pipes lay above or just below ground, and the water can slowly drip near the root area of the plants (FAO, 1985), as depicted in figure 20. Underground pipes minimise the risk for the harvesting farmers to get in direct contact with the effluent (Tilley *et al.,* 2014).

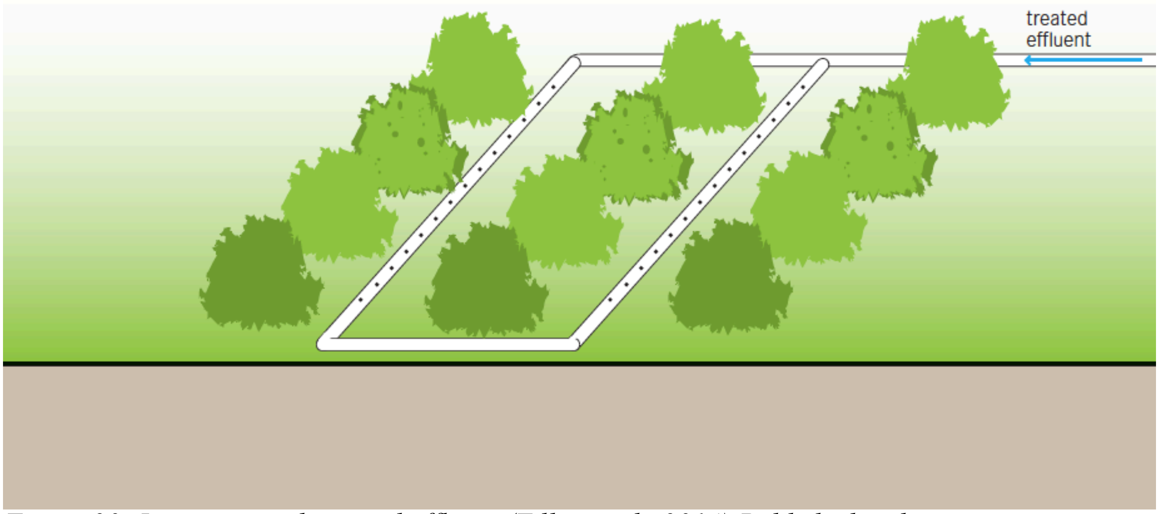


Figure 20: Irrigation with treated effluent (Tilley et al., 2014) Published with permission

Irrigation requires expert design and construction, moreover the construction and operating costs depends on scale of the irrigation system. Large industrial systems are very expensive, however, a small single system can be self-made and operated by trained farmers to lower costs (Stauffer [1], 2015). In both cases it is important for the treated effluent to be solids-free because the system is very sensitive to clogging (Tilley *et al.,* 2014).

6. Suggested Sanitation Solutions

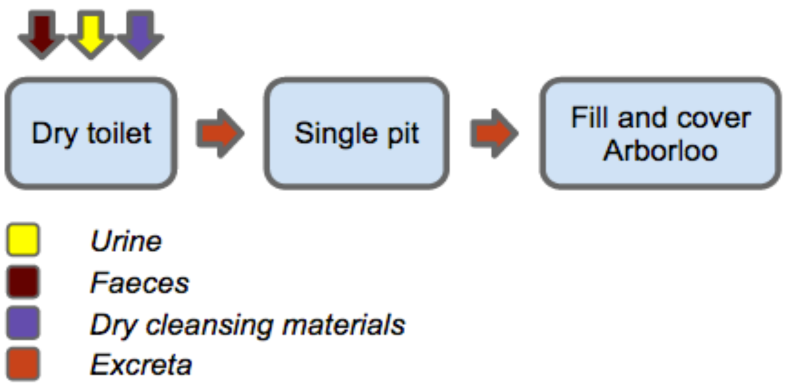
In this chapter the six chosen solutions are described and illustrated with flowcharts. The solutions are categorised in *dry* and *wet* systems. The scored points of each parameter are presented in diagrams. The scored points of each parameter are illustrated in separate diagram at the end of each section.

6.1 Dry Solutions

This part describes the solutions that do not rely on water. There are three solutions described Dry toilet single pit system with fill and practice of the Arborloo-principle, Dry toilet dual pit Fossa Alterna system with manual emptying and application, and Urine diverting dry toilet with application of rest products for agricultural use.

6.1.1 Solution 1: Dry Toilet Single Pit System, Practice of the Arborloo-principle

This solution is a simple dry toilet placed over a pit. The toilet and superstructure is moved when the pit is full. Afterwards a tree can be planted in the nutrient rich humus generated in the pit. The solution is described in flowchart 1.



Flowchart 1: Illustration of the components in solution 1

The only water consumed in this solution is if the user cleanse with water. Otherwise, if dry cleansing material is used, the toilet solution has no water consumption, which is positive in a dry climate. When the single pit is full, a new pit has to be dug, and therefore this solution requires large amount of space and is best suited for rural areas. The cost of construction is low as the components can be built without any expertise. The cost of operation is at a total minimum, as there is no removal cost and all of the elements except the pit lining are reusable when constructing a new pit.

Concerning comfort this solution is more comfortable than open defecation or the unimproved pit latrine due to the privacy the superstructure provides. Nevertheless, there are no measures taken to minimise odours, the excreta is visible for the user and flies are attracted to the toilet.

This method does not require any manual excavation of the pit, which lowers the risk of human contact with faeces. The maintenance consists mostly of continual cleaning of the toilet interface. However, as the solution does not depend on water, therefore, it is not likely that the user has water available in close connection to the toilet, which may complicate cleaning and handwashing. Hand washing can plausibly be carried out with alcoholic sanitisers, but in general, the prerequisites for good hygiene customs are lower compared to a water-based solution and the hygiene standard is low.

To make use of the nutrient rich humus in a full pit, a tree can be planted. This enables nutrient recycling to some extent. The simplicity of the solution can be a risk factor since people may compromise the building recommendations. Amateurs can build the pit, but may be ignorant to the importance of groundwater levels and secure radius from water bodies, which may lead to pathogen contamination or eutrophication.

This solution is mainly used by people living in rural areas and by those who cannot afford more complicated systems. Due to the primitive appearance of this solution, it has a low social acceptance. Many people prefer water-based solutions, since a water toilet is associated with a higher standard of living.

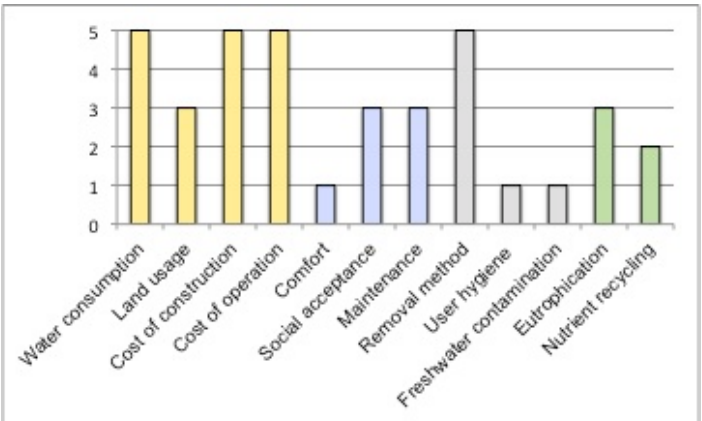
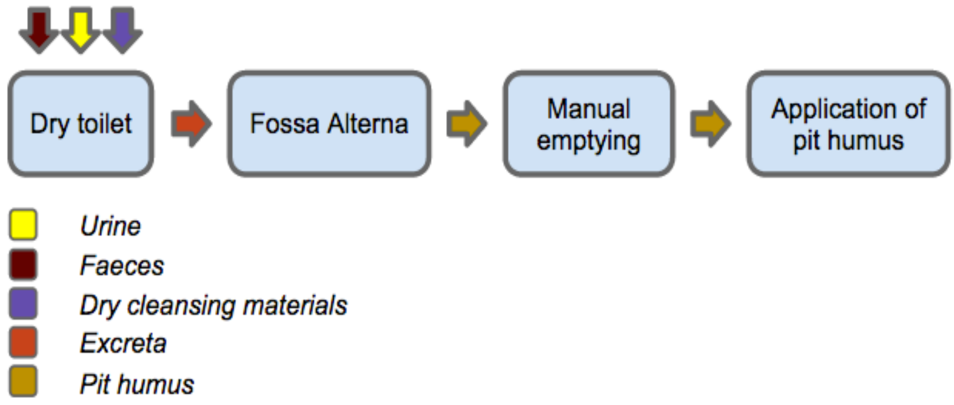


Diagram 2: Given parameter values for solution 1

6.1.2 Solution 2: Dry Toilet Dual Pit Fossa Alterna with Manual Emptying and Application

This dry solution is a built with a dual pit system, with alternating pits, which makes the system space efficient. The material is disinfected and decomposed in the tank, and after a certain resting time it can be used as fertiliser in agriculture. The solution is described in flowchart 2.



Flowchart 2: Illustration of the components in solution 2

Similar to other dry solutions, the only water consumed in this solution is if the user cleanse with water. Otherwise, the toilet solution has no water consumption. The system is built on the principle of two alternating pits, which restricts the land usage since the structure is permanent and does not require movement. The cost of construction is low as the elements can be built without any expertise. Two concrete slabs, two simple pedestals, one or two simple superstructures and the brick lining of the pits are the only necessary construction elements. The cost of operation is low due to the permanent nature of the system. The decomposition process converts excreta to disinfected pit humus and makes the rest products harmless to excavate and apply manually.

This solution is a comfortable dry toilet solution, and the ash and soil reduce the odours and the presence of insects, nevertheless, excrement is visible for the user. Regarding social acceptance this solution can be hard to understand without instructions, for example the necessity to continually add ash, leaves and soil after every usage. It can also be hard to convince users that the composed excrement is safe to handle manually. The maintenance that is required in this system is emptying of the pit humus and continual cleaning of the toilet interface.

The pit humus is manually removed from the pit, which is hygienic if the pit humus has decomposed sufficient time to reduce pathogens. With no water available it can be harder to establish a safe hand washing routine. An alternative is to carry out handwashing with alcoholic sanitisers but, by and large, the risk of disease transmission is high.

The Fossa Alterna system is an efficient method to recycle nutrients, as all of the rest products can be used in agriculture. The pit humus is nutrient rich and can cause eutrophication if applied nearby rivers and lakes. Concerning groundwater contamination, this method only requires a pit depth of 1-1,5 metres, therefore it is possible to build it as an over ground structure in areas with high groundwater levels.

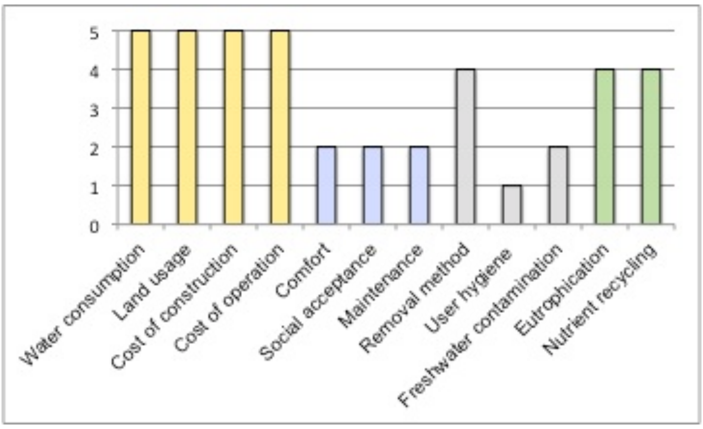
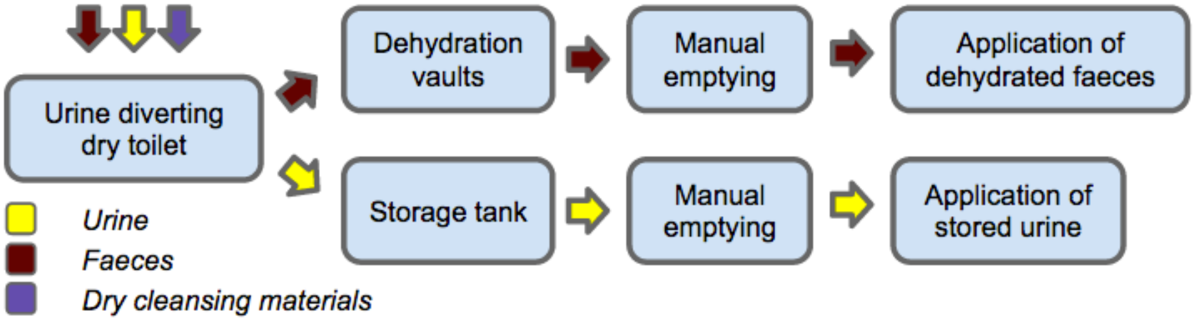


Diagram 3: Given parameter values for solution 2

6.1.3 Solution 3: Urine-diverting Dry Toilet, Application of Rest Products in Agriculture

This dry toilet system is built on the principle of not mixing faeces and urine. When these two are separated properly odours are reduced and decomposition is accelerated. The solution is described in flowchart 3.



Flowchart 3: Illustration of the components in solution 3

A urine-diverting dry toilet construction is relatively simple and the material and can be purchased locally. The solution is land use efficient, since only space enough for two dehydration vaults is necessary. Water consumption is minimal, the only water needed is for the regular cleaning of the toilet pedestal. There are no operation costs, except if reparation is needed.

The user needs instructions how to use the urine-diverting pedestal. If the diversion system is not used correctly, the dehydration process might be disturbed and the urine can become unreliable to use as fertiliser. The pedestal can be complicated to use for small children or physically disabled people. The odours and the occurrence of insects are reduced, compared to other dry solutions, due to ventilation and the fact that the faeces are drier, since the urine is separated. This system requires handling of urine and dehydrated faeces, which some people may find uncomfortable. Frequent maintenance is mandatory, there must be a supply of soil and ash to apply after every usage. When one vault is full, the pedestal must be moved to the other vault, and full urine tanks must be replaced.

Like other dry solutions, it may be complicated to establish a proper hand washing routine due to lack of water available in close connection to the toilet. This contributes to a low hygiene standard for the user.
There are two removal methods in this system, removing the urine tanks and emptying the dehydration vaults. The urine is sanitised after the required time of storage and is safe to handle.

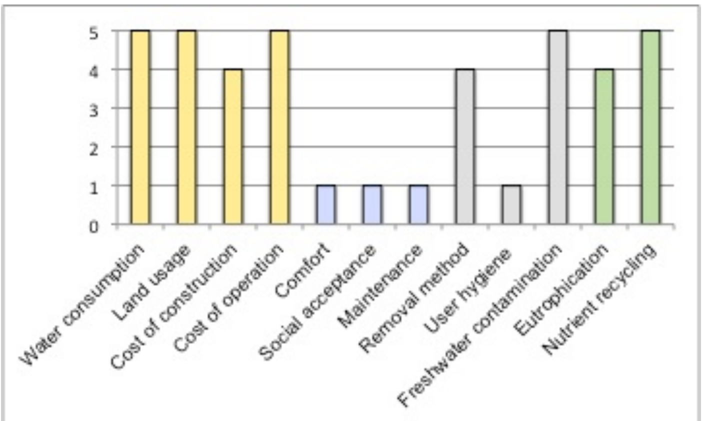


Diagram 4: Given parameter values for solution 3

The solution can be built in areas that are sensitive to flooding, due to the waterproof vaults and urine tanks. Moreover, the system reduces the risk of ground- and freshwater contamination. Nutrients in both urine and faeces can be recycled for agricultural activities. However, if either the urine or the dehydrated faeces would be disposed carelessly, the system could be a source of eutrophication.

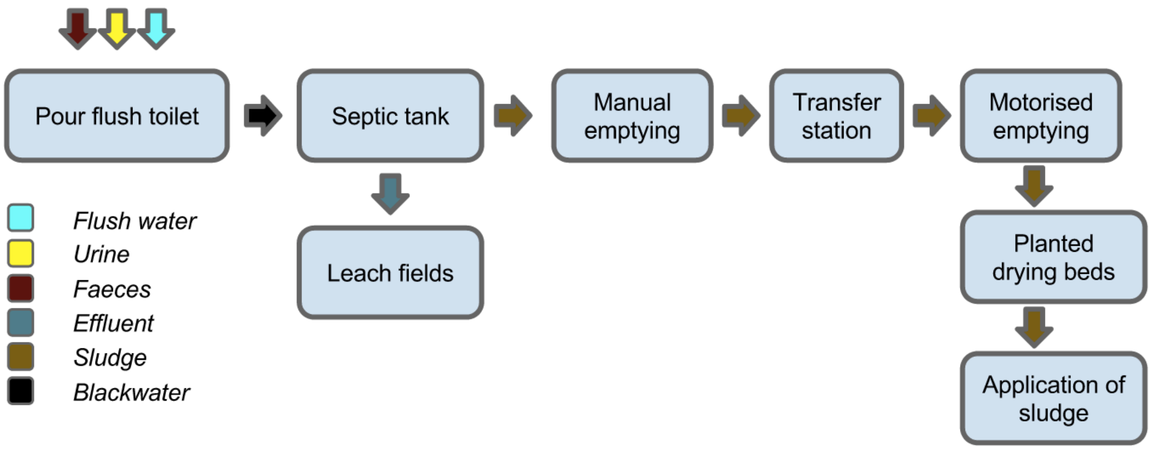
6.2 Wet Solutions

This part describes the solutions that are using a pour flush toilet as the first interactive step in the sanitation system. The treatment of effluent varies in the solutions, whereas the treatment and application of sludge is fairly similar in the three options. In general, a wet solution is more expensive than a dry solution due to the water consumption and more advanced technique.

The disclosed water-based solutions are *Pour flush toilet with septic tank and leach fields, manual emptying*, *Pour flush toilet with septic tank and leach fields, motorised emptying* and *Pour flush toilet with septic tank and solids-free sewer system.*

6.2.1 Solution 4: Pour Flush Toilet with Septic Tank and Leach Fields, Manual Emptying

This system consists of a pour flush toilet connected to a septic tank that separates the solids from the effluent. The sludge is emptied manually and moved to a transfer station, thereafter transported to the planted drying beds for further treatment. Later on it is used as fertiliser in agriculture. The effluent dissipates in the ground through a leach field. The solution is described in flowchart 4.



Flowchart 4: Illustration of the components in solution 4

Since a pour flush toilet is used, the water consumption can be varied in this solution according to prevailing water supply. However, water must be used to some extent to prevent clogging. In comparison to other wet systems, this solution is a low cost alternative with a relatively simple construction and uncomplicated maintenance. In the construction process expert knowledge is required, especially during the construction of the leach fields. Due to the large land usage of the leach field it is suitable for rural households in towns that are sparsely populated. The transfer station is usually placed relatively near the households, whereas the drying beds are preferably located further outside of the city due to odour and health risks. Since the drying beds can be far from the households, the placement can be flexible and strategically placed in areas that are less lucrative and inadequate to use for other activities. Planted drying beds require trained staff to operate and maintain the system, which increases the total cost of this solution. The transfer station occupies a certain amount of land at potentially attractive plots. However, the presence of a transfer station is likely to reduce unorganised dumping and has overall positive effects for the society. Many households share a transfer station, which contributes to lower transport costs for the removal of sludge, assuming that the planted drying beds are located far from the community.

The pour flush toilet is generally socially accepted since it is considered a high status symbol. Having access to water also facilitates hand washing. However, a prominent risk is that people do not prioritise to buy soap, which is crucial to enhance the hygiene quality, but overall the hygienic level of this solution is high.

Concerning maintenance, the flush toilet requires regular cleaning in order to maintain an acceptable hygiene standard and to prevent clogging. Even though a standard septic tank has the capacity to be emptied more seldom, the manual emptying requires emptying every year to ensure that the sludge is in a liquid state. The transfer station enables manual emptying which is economically beneficial for the user and prevent that owners neglect to empty the tank due to the cost of motorised emptying. However, a potential risk with manual emptying is human contact with the hazardous untreated sludge. Protective clothing and equipment are necessary, but due to ignorance or lack of resources this may not be prioritised.

The septic tank has a low reduction of pathogens, solids and organic material, and the effluent is not disinfected. If the leach field is not constructed satisfactorily, it can lead to that effluent contaminates the groundwater and soil. During rain season there is a risk of flooding, and oversaturated soil may reduce the effectiveness of the leach field. Moreover, if untreated effluent is let out in surrounding water bodies it can contribute to pollution and eutrophication in freshwater and through an extensive information campaign and courses. The sludge is treated in planted drying beds and can be used as fertiliser in agricultural activities. If the layer design is efficient the leachate pose a low risk of contamination. Moreover, the quantity of this water outlet is relatively small and the likelihood of severe consequences is low. Groundwater contamination is unlikely, nevertheless, the vegetation and sludge in the planted drying beds may attract birds and insects that can become disease vectors.

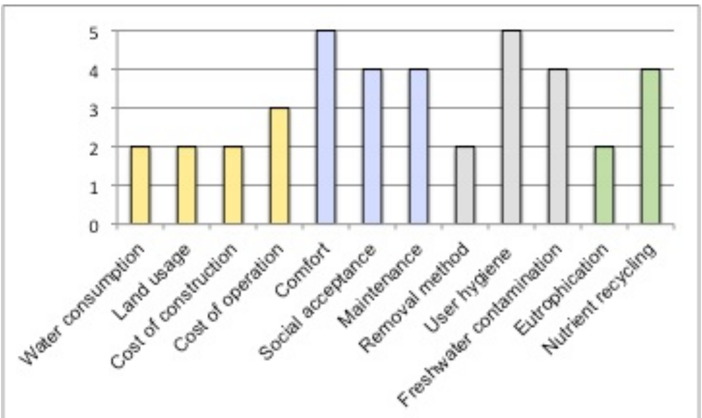
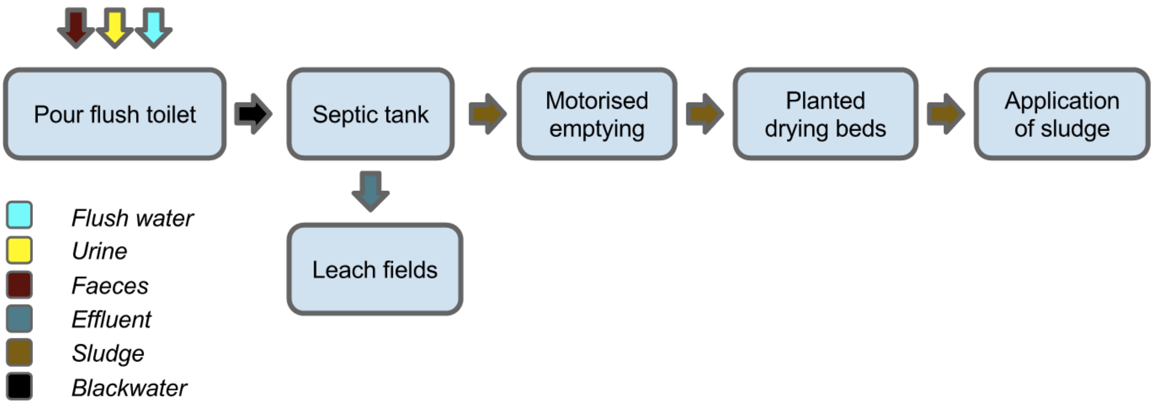


Diagram 5: Given parameter values for solution 4

6.2.2 Solution 5: Pour Flush Toilet with Septic Tank and Leach Fields, Motorised Emptying

Solution number 5 consists of a pour flush toilet connected to a septic tank. The tank is emptied by truck, with a frequency of two to five years, depending on the capacity and number of users. The sludge is placed in planted drying beds and after disinfection, it can be used for agricultural activities. The effluent dissipates in a leach field. The solution is described in flowchart 5.



Flowchart 5: Illustration of the components in solution 5

The water consumption can be regulated in this solution, however there is a minimum amount of water needed to prevent clogging. The leach field requires a certain amount of unexploited land and is therefore not recommended in dense urban areas. In addition to this, the motorised emptying demands trucks. However, trucks cannot operate in neighbourhoods with too narrow roads. The construction is relatively simple compared to sewerages and the main cost of construction is when acquiring the septic tank and under installation of the leach field, since professional guidance is essential. The maintenance is uncomplicated as long as the flush toilet is cleaned regularly and the tank is emptied with recommended frequency. Therefore, the operation cost consists mainly of labour and fuel, associated with the transport from the septic tanks to further treatment. Nevertheless, the motorised emptying is performed less often than manual emptying, which means that the higher cost is spread over a longer period of time.

The pour flush toilet is likely to have a high social acceptance because of its modern appearance, no visual discomfort and the odours and flies are not as extensive as in dry solutions. The access to water enables hand washing, however, the usage of soap is crucial to enhance the hygiene quality and there is a risk that people do not prioritise to buy this due to restrained assets. The fact that the excrement is flushed away highly reduces the risk of human contact with faeces.

The risk of spreading pathogens is lower with motorised emptying compared to manual emptying since the sludge is stored in a tank on the truck, if operated correctly there is no human contact with faecal sludge. A professional often operates the sludge truck, which increases the probability of correct workmanship. Moreover, it is more likely that a professional invests in the correct safety equipment, since it will be used on an everyday basis, in contrast to a private septic tank owner that only empties the tank once a year. Reluctance to pay for the motorised emptying might lead to illegal dumping and uncontrolled outlet of faecal sludge in the surrounding environment, that may cause eutrophication and pathogenic pollution in nearby watercourses.

Pathogens, solids and organic material are not effectively reduced in the septic tank and therefore the effluent is not disinfected. Heavy precipitation may, due to oversaturated soil, reduce the effectiveness of infiltration in the leach fields, which might lead to contamination of groundwater and surrounding water bodies.

The sludge is treated in planted drying beds, which may attract birds and insects that can become disease vectors. The sludge quality varies depending on the efficiency of the drying beds and the sludge can eventually be reused as fertiliser in agriculture. Leachate from the planted drying beds may pollute the surrounding environment and groundwater if the gravel layers in the drying beds are inefficient, but the outlet is relatively small, which contributes to that the risk of severe consequences is considered low.

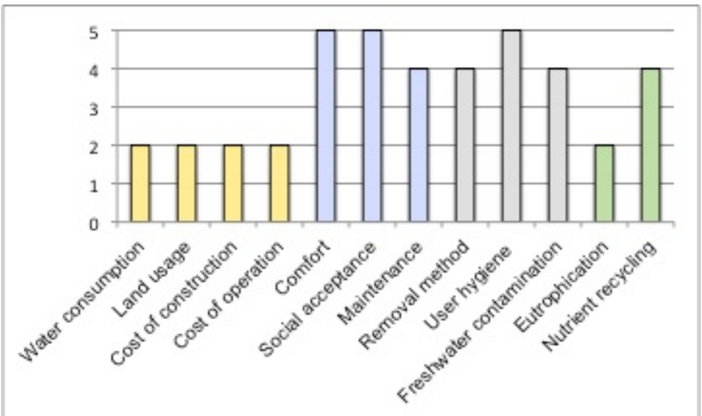
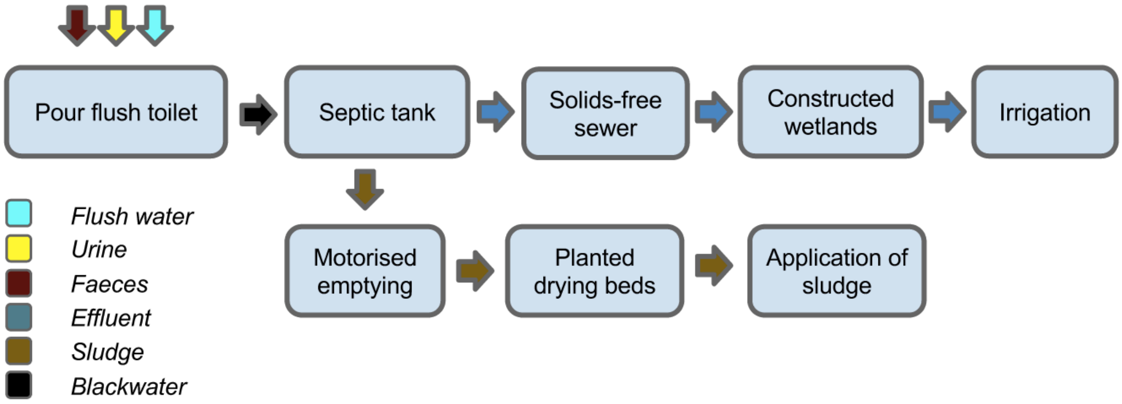


Diagram 6: Given parameter values for solution 5

6.2.3 Solution 6: Pour Flush Toilet with Septic Tank and Solids-free Sewer System

In this solution the blackwater is diverted to a septic tank for sedimentation. The effluent needs further treatment and is transported through a solids-free sewer to a centralised treatment facility. In this case the treatment of effluent is performed in constructed wetlands and the sludge quality is improved in drying beds. The solution is described in flowchart 6.



Flowchart 6: Illustration of the components in solution 6

Since the first step in this solution is a pour flush toilet, the water consumption can be varied, and costumed to the prevailing water access. The solids-free sewer is less expensive to build than a conventional sewer network and requires expert design and construct. Moreover, the pipes must be flushed periodically to prevent blockages. It is also of importance that the septic tank is emptied with recommended frequency. This is performed using motorised emptying and transportation. The motorised emptying, the planted drying beds and the constructed wetlands, all require trained staff to conduct the essential maintenance and continual control measures. Therefore, the main operation cost consists of staff expenses. In this study, a solids-free sewer network is the most expensive to build and operate. In order for the sewer network to be efficient and economically sustainable this solution must be built in towns and dense villages. However, the roads must be accessible to enable emptying of the septic tanks with trucks.

The pour flush toilet is likely to have a high social acceptance because of its modern appearance, no visual discomfort and since the presence of odours and flies is not as extensive as in dry solutions. The maintenance for the toilet owner consists mainly of regular cleaning of the user interface, since the other phases in maintenance are performed by an external employee, such as the driver of the emptying trucks and the staff of the drying beds. However, it is important that the owner is responsible and do not throw any undesirable material in the sewer since the system is sensitive for clogging.

The motorised emptying reduces the risk of human contact with faeces, since the sludge is stored in a tank on the truck. This removal method is relatively safe in the aspects of hygiene, presuming that the emptying and transportation are performed correctly. Hand washing after using the toilet is facilitated by the presence of water. However, the usage of soap is essential to enhance the hygiene quality.

There is a potential risk of leakages when using this sewer network. If leakages occur they can be hard to localise and therefore difficult to repair. Untreated effluent that leaks from the sewer can spread diseases if the wastewater infiltrates the groundwater or watercourses that are used for drinking water. The high concentration of nutrients in the untreated effluent might also lead to eutrophication and pollute the surrounding environment. The efficiency of the wetlands is important to establish in order to ensure the water quality and prevent the discharge of pollutants. Moreover, responsible management when building the wetlands is crucial to prevent damage of the environmental surroundings. The sludge is dehydrated in planted drying beds and the overall quality is improved, which makes it suitable to use as fertiliser in agricultural activities. Leachate can be a source of contamination if the gravel layers in the drying bed are inefficient.

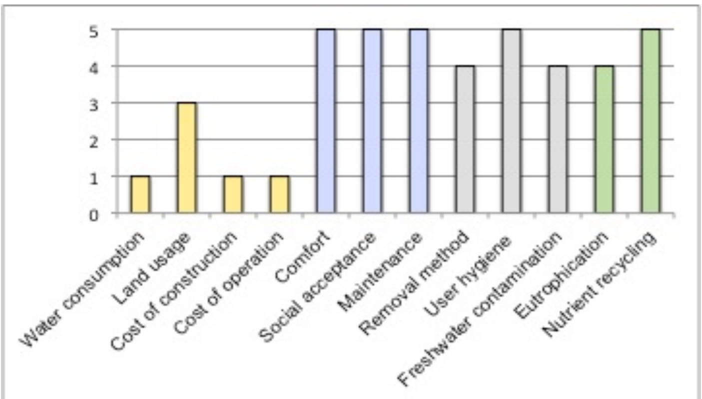


Diagram 7: Given parameter values for solution 6

7. Comparison and Result

The Multi Criteria Analysis is presented in table 1. The parameter weights for each study area are multiplied with the scored point for each solution, thereafter summarised in order to obtain the total score for each study area, an explanation of the calculation can be seen in appendix 1. The alternatives that scored highest for each area are marked with green at the end of the table.

Table 1: Multi Criteria Analysis with parameter weights and scored points for each solution.

MCA	Cochabamba	Tiraque						
	Parameter Weight	Parameter Weight	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources								
Water consumption	3	2	5	5	5	2	2	1
Land usage	3	1	3	5	5	2	2	3
Cost of construction	3	3	5	5	4	2	2	1
Cost of operation	3	3	5	5	5	3	2	1
Usage								
Comfort	2	2	1	2	1	5	5	5
Social acceptance	3	3	3	2	1	4	5	5
Maintenance	1	1	3	2	1	4	4	5
Hygiene								
Removal method	1	1	5	4	4	2	4	4
User hygiene and handwashing facilities	3	3	1	1	1	5	5	5
Risk of freshwater contamination	3	3	1	2	5	4	4	4
Long-term Environmental Aspects								
Eutrophication	1	2	3	4	4	2	2	4
Nutrient recycling	1	3	2	4	5	4	4	5
	Total Cochabamba		**84**	**93**	**94**	**88**	**90**	**88**
	Total Tiraque		**80**	**90**	**93**	**92**	**94**	**95**

The conducted Multi Criteria Analysis shows that in peri-urban Cochabamba, solution 3, *Urine diverting dry toilet with application of rest products for agricultural use* scored the highest rating. The result indicates that this is the most applicable improved sanitation solution in Cochabamba. In Tiraque, the solution with the highest score was solution 6, a *Pour* *flush toilet with septic tank and solids-free sewer system*. The generated results correspond well to the group and through an extensive information campaign and s expectations and seem applicable in the study areas. Nevertheless, small differences in the final result implicate that more than one solution is plausible.

In Cochabamba, the MCA shows that water-based solutions are less appropriate due to restrained water access and potential land use conflicts. The results in Tiraque show a low variety and indicate that many of the alternatives could be suitable, which is in direct correlation to the fact that Tiraque is a more resourceful area. Solution 1 receives a significantly lower score than the other solutions in both areas, which could be explained by its primitive nature.

8. Implementation

In this chapter implementation ideas for the two improved sanitation solutions for each area are presented. Based on the MCA result disclosed in chapter 7, the suggested solution for peri-urban Cochabamba is the *Urine diverting dry toilet with application of rest products for agricultural use* and for Tiraque the *Pour flush toilet with septic tank and solids-free sewer system* is the proposed idea. In order to solve the Bolivian sanitation crisis in a long-term-perspective, it is of utter importance that the implementation strategies of the new technologies is well elaborated, continuously updated and that the ideas are accepted by the local community to prevent the inhabitants of falling back into old habits.
The chapter handles the two study areas separately, and is subdivided in the sections *information campaigns* and *business strategies*. The information campaigns are necessary to convince the inhabitants about the new ideas and elaborate business strategies are essential to sustain the system and reach a continuous and a prosperous future of the solution.

8.1 Implementation in Cochabamba

The prevalent economical situation in peri-urban Cochabamba hinders the possibility of a large-scale distribution of the new solution. The urine-diverting dry toilet (UDDT) is relatively inexpensive, but there are people in this area without margins for this kind of investment, and therefore an external investor is required to provide financial aid in the initial phase. The capital may come from a non-governmental organisation (NGO) or the municipality budget, but currently many of the neighbourhoods are informal settlements that do not receive funding from the Cochabamba municipality. Due to this issue, the most realistic scenario is that implementation is funded by a well-established NGO.

In order to achieve a successful implementation, the first step is to organise tutorial workshops where people are encouraged to change their current sanitation situation and learn more about the suggested alternative. Thereafter, local water cooperatives can be in charge of acquisition and distribution of the material needed for the construction of the system.

8.1.1 Information Phase in the Peri-urban Area of Cochabamba

The fact that Bolivia is a plurinational state and that Cochabamba is a rapidly growing city may complicate the implementation since different customs and traditions are deeply rooted among the varying groups of inhabitants. The issue with social acceptance is therefore a crucial obstacle to overcome. Thus, it is important to break the taboo about these topics through education of the health risks of a poor or non-existent sanitation system.

In a segregated class society with many different religious and political perceptions it might be difficult to break the taboo and talk about toilets and hygiene customs. These are sensitive subjects that people in general are reluctant to discuss. The current general opinion, that the ownership of a water-based toilet is high status, complicates the implementation phase for the urine-diverting dry toilet.

In order to raise the awareness about the sanitation issue, an advertising campaign to propagate the UDDT needs to be conducted. Advertising strategies will include information posters in the neighbourhood, door knocking, workshops, discussions in public spaces and handouts of informative pamphlets.

UDDTs are installed in schools as a promotional and pedagogical strategy. The teachers receive education in how to use and maintain the system, in order to show the children how the system works. This method enables to spread the word among the younger inhabitants and their families, and teaches them about hygiene and disease spreading. Moreover, the teachers are provided with informational pamphlets and pedagogic material to use in the classroom continuously over the years to ensure knowledge regrowth. This will hopefully improve the consciousness of sanitation among the future generation of Cochabamba.

By organising external educational workshops in easily accessible places, the likelihood of a high attendance increases. The suggestion is that representatives from the NGO travel and visit the different informal settlements instead of having the workshops in the city center. Since the UDDT differs from ordinary toilets, it is important to emphasise the benefits of the technology and explain the positive effects of a large-scale use of the toilet. The workshops will address how to build and maintain the UDDT, how to use it and how to handle the rest products. These focuses are all essential to discuss, since misoperation of the toilet may turn it to a source of pollution. Moreover, the workshops can inspire and aid local business owners to get involved and identify new job opportunities.

To succeed with these workshops and advertisements, many factors have to be taken in consideration. For example, not all inhabitants are literate and may need supplemental descriptive pictures and not only text manuals. Moreover, many people have another native language than spanish, even though the vast majority speaks and understands it. If the workshops are held in their own tongue the message may be easier to perceive and the people may show more reliance for someone speaking their language. Since few people speak the minority languages, it may be a problem to find people from the NGO that can realise this task. This problem can however be solved by engaging local ambassadeurs, perhaps persons from the local water cooperative, that form a link between the NGO and the neighbourhoods. The local ambassadeurs can be volunteer workers or employed by the NGO. Volunteers among the inhabitants are preferable in many aspects, both in order to save money and avoid corruption, but more importantly, to assure the community of authentic goodwill in the campaigns.

The farmers surrounding Cochabamba play an important role in the success of this implementation strategy since it is central that the rest product from the UDDT becomes a demanded fertiliser. It is therefore fundamental that the farmers are informed by the benefits of using dehydrated faeces and urine as fertilisers. It may be challenging to convince the farmers that the rest product is hygienic, and therefore the information campaigns are important. The information will reach the farmers through the local market and by personal visits.

After the process of informing the people, the obstacles of social acceptance are hopefully decreased. When the introduction process has succeeded and the system is accepted and adapted in the society, aid from NGOs is no longer needed. Regular monitoring is necessary to sustain a functional system. Moreover, knowledge regarding how to maintain the solution and take care of the rest products has to be continuously passed on, to business owners, distributors and farmers, in order to assure a sustainable solution.

8.1.2 Business Strategies in the Peri-urban Area of Cochabamba

The implementation is dependant on well-managed disposal of the rest products, to avoid illegal dumping. The dense areas in peri-urban Cochabamba does not provide much farmland and therefore the urine and dehydrated faeces, generated in the UDDT, need to be used for agriculture elsewhere. If the initial informational campaigns have positive outcomes, they will hopefully create a demand for the rest products among farmers, whom are dependant on fertilisers in their occupation.

A system where the UDDT users can exchange their full tanks for empty ones is introduced. In a start up period this could be achieved in a similar way as the water distribution system, with privately owned transportation trucks, which collect the urine tanks and dehydrated faeces from the households and sell the products to farmers. In the initial phase the truck drivers are employed by NGOs and the trucks distribute the fertilisers to the farmers free of charge, to promote the products as cheap and effective alternatives to expensive chemical fertilisers.

After the initial promotional phase, the solution is hopefully socially accepted and a demand for the natural inexpensive fertilisers has been established. Henceforth, the financial aid from NGOs is phased out and replaced with funding generated from the business of selling fertilisers to farmers. The price of the dehydrated faeces and urine tanks will be less expensive than other fertilisers, which will prevent people of going back to old habits. Due to the high need for tank exchange, truck driver might be a full-time job.

An alternative to the truck system that could be implemented in the longer perspective, is that the water cooperative, or a shop owner in each neighbourhood obtains the responsibility of interchanging the tanks and that each person leave their own tank at this interchange point. This centralised solution would also create jobs and generate an income for both the family, that sell their urine tank for a small fee, and for the cooperative or shop owner, that can sell bigger quantities for a larger sum, directly to a farmer. The transports in this alternative would be more efficient compared to the solution when trucks drive to each household. However, this system requires more stability and is therefore better to implement when the system is already in use. To ensure the sustainability of this business it is positive if long-term trading relations between the shops and farmers are established, since both the farmer and the shop owner are depending on a continuity in the deliveries.

Moreover, shops where people can buy essential material to construct a UDDT have to be established. This business can either be incorporated in existing hardware stores or new shops can be built. The staffs operating the store receive further education, so that questions concerning the system and its benefits can be answered on site. If problem with the UDDT occurs, the user will be able to receive help from the shop staff. The shop owners and the distributors will strengthen the economy and the independence of the peri-urban area.

8.2 Implementation Strategies for Tiraque

The sewerage in Tiraque is old and the treatment plant does not work satisfactorily. The proposal is to take advantage of the already existing sewerage and incorporate it in the suggested solution. The pipe network needs to be renovated and complemented with new sewers, planted drying beds, constructed wetlands and pipes for irrigation. The *Pour flush toilet with septic tank and solids-free sewer system* is an expensive solution that requires employees and regular maintenance. This makes the implementation of this system more or less depending on a well-functioning municipality. Tiraque is a small town without informal settlements, the municipal governing is relatively stable and have the possibilities to meet these requirements. In order to repair the old sewerage and implement new technologies, start investments from external investors is likely necessary, since the municipal budget is restricted. The municipal board already cooperates with NGOs and hopefully this collaboration can continue. Hopefully, when more actors are engaged in the implementation process, the risks of corruption and mismanagement of resources are reduced.

The suggestion is hence that the municipal board of Tiraque cooperates with NGOs, which can handle the acquisition of material, organise the distribution and manage the information campaigns.

8.2.1 Information Phase in Tiraque

In the town of Tiraque, the social acceptance issue is not a major challenge since a majority of the inhabitants already have pour flush toilets. The objective with this information campaign is to encourage the homeowners to invest in a septic tank, which is necessary in order to convert the old sewerage to a solids-free sewer. Moreover, the information campaign would aim to improve the citizens' environmental awareness.

Workshops are organised to inform the inhabitants about the benefits of the sewage system and the importance of improved sanitation. The importance of hand washing routines and the usage of soap can be taught and reinforced by teachers in school. Furthermore, the workshops will include the overall operation of the solution, what amount of water that is required to prevent clogging and how to solve it if it occurs. The information meetings are important, and after completion of the course, the participants are given a handbook with advice and descriptive pictures for children and illiterate. A further aim of the workshops is that, if problems with the septic tanks occur, the users will be able to repair the tank themselves.

The fact that Tiraque is a small town will facilitate the information phase since it is easier to reach and get in contact with the people. This will hopefully make it less problematic to start the discussion about sanitation and the existing environmental and health problems. Tiraque is dependent of agriculture and caretaking of the cropland, therefore the sludge reuse and irrigation system is probably of interest for all of the inhabitants. The farmers may be reluctant to the usage of sludge fertilisers and effluent for irrigation in the beginning. Nevertheless, if they are taught about the positive effects and the efficiency of the planted drying beds and constructed wetlands, it will probably be easier convincing them to use the new products.

After conducted information campaign, expectantly, the inhabitants have a positive attitude towards the sanitation conversion, which is favourable for the implementation since the transitional phase may be inconvenient. For example, the municipal budget is likely to be restrained during the implementation phase, and people will have to bear with disturbances, such as noise and dust, during the construction of the septic tanks. If people are positive to the idea, community based activities or the involvement of business owners can enhance and accelerate the implementation process.

8.2.2 Business Strategies in Tiraque

As earlier mentioned, the new system requires staff to manage the new sanitation system, hence new job opportunities are generated. In order to finance the personnel costs, a general sewerage fee is introduced. A fee may exclude the inhabitants with the lowest income in the society, but with municipal subventions, this system can be accessible to everyone. Due to the municipal governance of the system, private business owners can only be involved through public procurement. This is associated with a high risk of nepotism and corruption, and might not be an optimal solution in this area. Nevertheless, to ensure the provision of sanitation services for inaccessible, not economically viable areas, this solution may be unsuitable for privatised management. In general, political issues are sensitive subjects in Bolivia, and with the Cochabamba water war in recent memory, privatisation of water and sanitation services is not preferable.

One example of a new local job generated is truck driver, who drives the trucks for emptying and transportation of sludge. In order to avoid damages and solidified sludge in the septic tanks, the staff that operates the emptying and transportation perform regular inspections. If the profit margin of the company is not enough, they might also operate in nearby areas of Tiraque, provided that there are households with septic tanks. The people that work with the emptying and transportation are educated about the importance of protective clothing and how to perform secure emptying. A community-based water cooperative can facilitate the scheduling and organisation of emptying routines.

The drying beds are located outside the neighbourhood, and the location is inspected and approved by an expert associated with the NGO. It is of importance to locate the drying beds sufficiently far away from inhabited areas to avoid inconvenience and disease spreading, yet it must be within a profitable range for transportation by trucks. Management and maintenance of the drying beds require trained staffs, which generate another job opportunity. The most intense work is when receiving sludge trucks, but the work mostly consists of maintenance and ensuring that there are no leakages to surrounding environment.

The sludge from septic tanks is greatly reduced and the quality is improved in the planted drying beds. The remaining treated content can be sold to local farmers. In order to make it socially accepted it is important that the information campaign succeed in convincing the inhabitants of the benefits with sludge reuse. Moreover, the dehydrated sludge will be less expensive than chemical fertiliser alternatives.

The effluent in the sewer system is diverted to the constructed wetlands where the pathogens and nutrients are reduced. Operating the wetlands consists of carrying out regular inspections, maintenance and surveillance. This job is suitable for persons living in near distance of the wetlands. Later, the cleansed wastewater is diverted through drainage pipes in the wetlands to nearby fields for drip irrigation. This will greatly reduce the use of freshwater in the agriculture. The possibility of irrigation will likely compensate for the unwillingness to have constructed wetlands nearby. The landowners perform Operating and maintenance of the irrigation pipes, since their farmland benefits from the irrigation.

9. Discussion

To conduct the bachelor thesis within the given timeframe, delimitations, simplifications and assumptions were necessary. This chapter discusses and analyses the results and implementation strategies. The intention is to briefly evaluate the plausibility of successful implementation in reality, with all its challenges.

The implementation strategies are based on the assumption that, after an introduction phase with information campaigns, all the inhabitants in the study areas will be receptive and eager to assimilate to the new systems and routines. In reality, there will be major challenges concerning central mismanagement, political instability, poor maintenance and lack of resources. Due to the complexity of the situation, the results of the Multi Criteria Analysis may be inaccurate and alternatives to the suggested solution require further discussion.

The topics (*Resources, Usage, Hygiene* and *Long-term environmental aspects*) and their corresponding parameters in the MCA were stated after literature studies and consultation of a PhD-student, with experience from the area. Still, the selection is likely subjective to some extent, due to the imprinting of Swedish experiences and perceptions of hygiene and sanitation. The effects of this may be that the chosen parameters are not completely representative of the, in reality, most important factors in the studied areas. Since no interviews were conducted with the inhabitants, assumptions were inevitable. By consulting residents in the study areas, the accuracy of the chosen parameters, and hence the result of the MCA, could have been improved.

The issue of not knowing the most important factors for the inhabitants in the study areas remains during the choice of parameter weights comparing Cochabamba and Tiraque. The numbers are estimated and might not correspond to reality. Moreover, the differences in the character of the parameters complicated the scoring. Some parameters, such as *costs,* have a high level of quantifiability, whereas other parameters, such as *social acceptance*, are scored with subjectivity. Nevertheless, the points were deliberately rough estimates of the perceived level of importance and efficiency.

It was problematic to distinguish and estimate the costs, since the numbers rely on several external factors, and some systems have expensive central components where costs are shared between many users. The possibility of investments from external investors such as NGOs has been disregarded in the MCA, which may have lead to unnecessarily harsh assessments of the cost factors. There is a high probability that NGOs are interested to be involved, since such organisations already are present and working in the study areas, and hopefully will continue with this in the future.

Some of the parameters were restrictive, meaning that the solution would be impossible to implement if the resource demand of the technology exceeds the available assets in the study areas. One example of this is the parameters *water consumption* in Cochabamba; under the current circumstances with severe water shortage, a water-based solution with high demand of water would have been unrealistic to implement. This has not been stated expressly in the text but is implied due to the low scoring in the MCA.

The solutions that scored highest in the MCA were further analysed and given implementation strategies. In both study areas there were small margins to the solution in second place, which opens for discussion about alternative options.

A solution that had a similar score in the MCA, and also should be considered in peri-urban Cochabamba, is the Fossa Alterna system. This system does not provide good protection against environmental contamination, however, its simplicity makes it more probable to be used and maintained properly. The only rest product is pit humus, which resembles soil and may be less unpleasant to handle than the dehydrated faeces and urine from the UDDT. The Fossa Alterna construction, with one hole for both urine and faeces, is similar to the well-known single pit latrine. This may result in that the Fossa Alterna system would have less need for advertising and information campaigns, compared to if the UDDT would be implemented. The Fossa Alterna system is not as dependent on the farmers' demand for rest product disposal, since there are no urine tanks. However, the probability of the farmers not having need for fertiliser is low.

When comparing the two solutions, assuming that the systems will be properly used and operated, the most suited solution is the UDDT. Nevertheless, the margins were small and the tipping point was the reduced risk for freshwater contamination and eutrophication. Reducing the risk of spreading pathogens in the freshwater is essential, both in the attempt of improving the overall health in Bolivia and in the battle against environmental contamination.

In Tiraque, the parameter *land usage* was considered less important than in Cochabamba, due to that Tiraque is a sparsely populated region. The solutions chosen in Tiraque require land that has to be spared from other activities, such as agriculture. The decision to give the parameter weight 1 for *land usage* in Tiraque may have been wrong, since the land in general is cultivated. This is of importance as agricultural crops are a major source of income, fundamental for the economy in Tiraque. However, the farmers that provide land for the constructed wetlands are likely to be positive to the establishment, since their crops will benefit from its irrigation possibilities. The planted drying beds are, on the other hand, less pleasant to have nearby due to the odours and high risks of pathogen spreading. This makes it unlikely that a private landowner will agree to the construction of drying beds on their land. A landowner might be convinced through economical compensation, but the most preferable solution would be to build the planted drying beds at land plots owned by the municipality.

The solution that scored the second highest for Tiraque, was connected to leach fields, that are very space consuming, which makes this alternative less appropriate in the context. Additionally, the UDDT was considered to be a plausible solution, but due to the fact that people are already used to water toilets there is a high risk of problems with social acceptance. Therefore, this alternative is not further discussed.

As earlier mentioned, the implementation strategies are based on a scenario where the inhabitants are positive to the new sanitation system and comply to the required routines impeccably. In reality, this state is nearly impossible to achieve. People are in general reluctant to change their habits and there will most likely be a transition time before the new technologies are entirely accepted. For example, in Cochabamba during the implementation of the UDDT, there is risk that men find it strange to sit down when urinating. To resolve this problem, the installation of a urinal connected to the urine tank is possible. This would cause additional costs, but is still a valid option if sitting down is shown to be a hindering factor. Moreover, the solutions are dependent on that individuals take responsibility for necessary emptying and cleaning. There are many explanations to why people would neglect the important maintenance and repairs, such as lack of money, time or knowledge. If the educational workshops are successful, the people are more likely to understand the necessity of eventual repairs and prioritise the unexpected costs, instead of regressing to the practise of open defecation.

The informal settlements of peri-urban Cochabamba are a result of high and rapid urbanisation. In general, people who move to the city want to improve their living standards and are conscious about social hierarchies. In the rich central part of Cochabamba, people are using flush toilets, which have resulted in that the flush toilet is a symbol of success. This will further complicate the implementation of the UDDT.

Another challenge with the urine-diverting dry toilet is the high risk of mismanagement of the rest products. Depending on the demand from farmers there will be different ways to get rid of these rest products. If there is a high demand, families will get paid and helped with the urine tank collection and the delivery to the farmer. This would be a positive outcome and strengthen the social acceptance of the solution. However, if there is a low demand, the families may not get paid and will have to carry their urine tanks in public, which might be considered as shameful. A problematic scenario would be that there is no demand for fertilisers or that the waste collection system is insufficient, which may result in illegal dumping of the rest products in the surrounding environment and nearby water bodies. This could make the UDDT a source of pollution that contributes to an increased risk of freshwater contamination and eutrophication. The fact that the solution is so dependant on the demand for fertilisers may seem fragile and risky, but currently the need is high, since farming is one of the main occupations in Bolivia today.

The highly populated peri-urban area in Cochabamba is constantly growing. Within a not so distant future this area might not longer be at the outskirts of town, but incorporated in the more central parts of the city. If the municipality acknowledges this area as a part of Cochabamba, more possibilities of building a functioning water-based sewer system arise. If the living standard is improved, there is a risk of gentrification, when more wealthy citizens move in and higher the status of the neighbourhood. An effect of this is that the price of land increases which may, in the long run, lead to that poor people are driven away. Another scenario is that the peri-urban area continues to be unacknowledged and one of the poorest areas in Cochabamba.

It is difficult to predict the future of the area, but regardless of the outcome, urine-diverting toilets are a good and flexible sanitation system, and moreover, a step in the positive direction for sanitation and health improvement. Permanent structures such as large leach fields or sewage systems are associated with larger investments and more difficulties in the event of a relocation or renovation of the neighbourhood. The predicted population growth in this area is high and a potential risk with the UDDT is excessive generation of rest products, which may exceed the demand for fertilisers.

The task to make the pour flush toilet accepted in Tiraque town, is likely to be less complicated than to introduce the UDDT in Cochabamba. The UDDT in Cochabamba involves learning a new concept whereas in Tiraque, the vast majority already are accustomed to the pour flush toilets. The already existing sewer network in Tiraque has to be connected to the new installations and this is much more technically demanding, compared to the UDDT technology. This requires expert knowledge, which may be hard to obtain in rural towns like Tiraque. Furthermore, the situation in Tiraque is stable and its solution can therefore be more advanced with more steps in the water treatment, and hence also more environmental-friendly. The treatment processes are however not as visual for the inhabitants as the UDDT processes in Cochabamba, since the wastewater treatment is performed in other locations. The goal to raise the environmental awareness in the society might therefore be difficult to reach. If the information campaigns succeed and people get more interested in environmental issues, it could be a step forward for sustainable development. Another positive outcome with the water-based solution, that has good hygiene possibilities and a complete water treatment process, are the decreased risks of disease transmission in Tiraque.

An environmental factor that has not been considered and that is a weakness of both implementation strategies is the potential presence of pollutants and microbial pathogens in sludge and dehydrated faeces. The usage of sludge as a fertiliser for human food production is controversial and there is an on-going debate around the world whether the use of sludge as a fertiliser really is safe. Fertilising with faecal sludge requires thorough controls of disinfection, to ensure that the sludge has sufficiently low levels of pathogens. Otherwise, the risk of disease spreading through faecal bacteria is high. To ensure the quality of the sludge, strict regulations of the sludge treatment processes and laboratory controls are necessary. This would require resources and competence to conduct, and the radical change will be difficult to enforce under current circumstances.

It is also likely that the sludge contains heavy metals and other pollutants such as chemicals, pharmaceutical residues and remnants of drugs that might be absorbed by crops or leak to nearby watercourses. The use of cocaine and other drugs are common in Bolivia and if faecal rest products are used in large scale, this has potential to become a major problem. The implementation strategies are based on the demand of sludge as fertiliser. If the quality of the sludge is not possible to guarantee, this demand would not arise, and the sludge may be disposed without nutrient recycling.

The study is designed to determine the most applicable solution in the Bolivian context, but the suggested solutions are most likely suitable in similar locations with comparable climate, economy and social circumstances. The lack of sanitation and freshwater is not an isolated problem that prevails in Bolivia, but a widespread issue worldwide. When comparing the UDDT and pour flush toilet, the UDDT is the most likely to be successfully implemented, regardless of location. The fact that the construction is flexible and can be built by the users themselves, makes it less dependent on a stable central organisation, which is advantageous in an informal settlement where inhabitants often are forced to move around.

Conclusively, the requirements of urban areas differ from the needs in rural towns. The peri-urban areas of Cochabamba are characterised by continuous change, unstable governance and limited resources for development, which demand a flexible and independent solution. Additionally, the current conditions in the area do not allow radical changes. As the most critical issue in Cochabamba, is to terminate the practise of open defecation, gradual improvements with small successive upgrades seems to be the right approach. The rural town Tiraque, on the other hand, is a more stable community where the townscape is less changeable and therefore, a complete sanitation solution is more realistic to implement. The municipal continuity and potential of cooperation among neighbours, enable to manage the complexity of a water-based sewage system, that also considers environmental impacts.

10. Conclusion

The study compares six plausible alternatives for improved sanitation and suggests the most applicable solution for the respective study areas. After conducted literature study, the conclusion is that the prevailing needs differ in peri-urban Cochabamba and rural Tiraque town. Hence, the sanitation solutions must be adapted to correspond to the circumstances in each study area.

The peri-urban Cochabamba needs a solution that is resource efficient and flexible. The conducted Multi Criteria Analysis, MCA, resulted in the suggestion that the urine-diverting dry toilet is the most applicable solution. A great challenge, in order to achieve a successful implementation, is to make the solution socially accepted, especially since the customs and traditions vary among the population. The implementation method involves non-governmental organisations, NGO, for financial and technical support in the conducting of an extensive information campaign and the establishing of new businesses.

The rural town Tiraque is a stable community and there are good possibilities to install a permanent and sustainable solution. The MCA for Tiraque lead to the suggestion of a pour flush toilet with solids-free sewer system, constructed wetlands and planted drying beds. The major challenge with the implementation of this system is to ensure maintenance compliance. Hence, the solution is dependent of a well-functioning municipality in collaboration with water cooperatives and an experienced NGO.

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Appendix 1:
Explanation of MCA calculation

MCA	Cochabamba	Tiraque		Solution 1 Cochabamba	Solution 1 Tiraque
	Parameter Weight	Parameter Weight	Solution 1	Explanation of calculation	Explanation of calculation
Resources					
Water consumption	3	2	5	3 x 5 = 15	2 x 5 =10
Land usage	3	1	3	3 x 3 = 9	1 x 3 = 3
Cost of construction	3	3	5	3 x 5 = 15	3 x 5 =15
Cost of operation	3	3	5	3 x 5 = 15	3 x 5 =15
Usage					
Comfort	2	2	1	2 x 1= 2	2 x 1= 2
Social acceptance	3	3	3	3 x 3 = 9	3 x 3= 9
Maintenance	1	1	3	1x 3 = 3	1x 3 = 3
Hygiene					
Removal method	1	1	5	1 x 5 = 5	1 x 5 = 5
User hygiene and handwashing facilities	3	3	1	3 x 1 = 3	3x 1 = 3
Risk of freshwater contamination	3	3	1	3 x 1 = 3	3 x 1= 3
Long-term Environmental Aspects					
Eutrophication	1	2	3	1 x 3 = 3	2 x 3 = 6
Nutrient recycling	1	3	2	1 x 2 = 2	3 x 2 = 6
	Total Cochabamba		**84**	15+9+15+15+2+9+3+5+3+3+3+2=84	
	Total Tiraque		**80**	10+3+15+15+2+9+3+5+3+3+6+6=80	