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# Sustainable sanitation –

*A case study in Yasmine and Awda informal settlements (Lebanon)*

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# PREFACE

This MSc thesis is my final work of the Master of Science in Water- and Environmental Technology at Norwegian University of Life Sciences (NMBU). The research is based on fieldwork undertaken from the 27$^{th}$ of January until the 3rd of March 2019 in Bekaa Valley, Bar Elias, Lebanon, aimed to find sustainable sanitation solutions in two refugee camps.

The study has been carried out in close collaboration with Norwegian Church Aid (NCA), International Orthodox Christian Charities (IOCC) and Multiconsult. My motivation for this thesis was based on a desire to choose a research topic that could be meaningful for others, and my interest in water and sanitation in developing countries. I sincerely hope this will contribute to improvements and implementation of a holistic sanitation system which will benefit the people in the studied camps.

Ås, May 14$^{th}$, 2019

Elisa Winger Eggen

## ACKNOWLEDGEMENTS

Working on this thesis has been exciting, challenging and educational. There is a lot of effort invested in the final version of the thesis, and the learning process to this point has been invaluable. Many have contributed to this work, whom I will like to thank;

First and foremost, my deepest gratitude goes to my main supervisor, Professor Petter D. Jenssen, for his enormous inspiration, engagement, valuable feedback and support along the way.

I would also like to thank Tor Valla (Multiconsult), Ioannis Georgiadis (NCA) and Manfred Arlt (NCA) for introducing me to this project in Lebanese refugee camps, where my education would be relevant and applied in practice. The issue and background for this study was presented to me during the summer of 2018, and I am very grateful for all their guidance and help both before, during and after the trip.

Furthermore, I would like to thank Fadi Suliman (Multiconsult) and Ziad Abdayem (IOCC) for their technical guidance and important feedback. A heartfelt thanks to my translator, Rita Saad, who helped me communicate freely with the refugees and carrying out the interviews and focus group discussions. I would also like to use this opportunity to thank Fadi Haddad (IOCC) for challenging me to try interesting Lebanese delicacies like grilled sautéed frog legs, lamb testicles and brain.

A special thanks to the people living in the refugee camps, for their hospitality and openness, and to all the children that made my days very fun and lovable.

Many thanks to my classmates for their support, friendship and humor throughout this period. I appreciate all the excuses you made to have endless lunch breaks and to eat ice creams in the sun.

Last but not least, I would like to thank my family; my mom and my dad, sister and brothers for their indispensable support.

## ABSTRACT

Lebanon is a relatively small country but has the largest concentration of refugees per capita in the world. One quarter of the population are refugees. As the Syrian crisis enters the eighth year, Lebanon has been a host to almost 1.5 million Syrian refugees. The crisis has placed a great constrain on public services, with demands far exceeding the capacity of institutions and infrastructure.

The water- and wastewater sector in Lebanon is characterized by unclarified roles and responsibilities with overlapping functions. Proper wastewater management is a national issue, and with the rapid influx of refugees and already constrained sanitation options, conditions in the refugee camps are especially challenging.

This thesis focuses upon two refugee camps located in Bar Elias, Bekaa Valley, Lebanon, currently hosting approximately 2200 people. The present wastewater- and sanitation solution at the camps consist of family toilets and showers inside each dwelling. Every household is connected to a wastewater network with separation of greywater (shower, sink, dish- and clothes washing) and blackwater (toilet). The greywater is pumped through the pipe network to a two-chamber septic tank, and then furthermore pumped to a soil infiltration trench for treatment, before effluent discharge into the irrigation channel nearby. The blackwater is stored in a holding tank, and frequently pumped out by a vacuum tanker. The trucks collect the content and transport it to an off-site wastewater treatment plant, and this is a costly procedure.

The soil type in the area was fine-grained silty clay soil which was assumed to have limited hydraulic capacity. The different wastewater streams generated in the camps were relatively low, thus the greywater sample analyzed in the laboratory was highly concentrated. The on-site greywater treatment performance was not optimal, and the design of the infiltration system should be changed. This could be done by adding a sand layer between the natural underlying soil and the gravel holding the infiltration pipes, and construct a mound system. The result will be a higher effluent quality, and the treated greywater could discharge into the irrigation channel without causing more pollution. To save water, the treated greywater should ideally be reused for flushing, gardening purposes or laundry washing.

Both grey- and blackwater should be handled on-site in a complex system to achieve more sustainable management and reuse of more wastewater resources on-site. Implementation of new technologies such as anaerobic baffled reactors followed by anaerobic filters or optionally upflow anaerobic sludge blankets, will make it possible to produce biogas as a source for energy. The biogas potential could increase by adding organic waste (food waste and animal excreta), and if urine diversion toilets are installed to collect the urine separately. The urine could be used as a liquid fertilizer, while the faeces could be used as soil amendment or solid organic fertilizer in the fields after being dewatered in sludge drying beds. If the assumptions to produce biogas with organic waste is too low and the area requirement is too high, mobile small wastewater treatment systems could be installed in the camps. These solutions are suitable in temporary refugee camps because they are easily transported anywhere.

The refugees were in general very open-minded and positive to changes. They were all convinced that if a more sustainable solution would benefit them, it should be implemented. The refugees receive training in self-management of the camp facilities, and participate in classes about water, sanitation and hygiene. This thesis recommends further interaction with the refugees to cultivate ideas and determine their ability to move forward and have a self-supportive system. Acceptance from the local people is a key factor for a successful project since they are the ultimate decision-makers.

**Keywords:** *Lebanon, Wastewater treatment, Separation of greywater and blackwater, Human excreta disposal, Refugee camps, Sustainable sanitation.*

## نبذة مختصرة

لبنان بلد صغير نسبيا ولكنه يضم أكبر تجمع للاجئين في العالم بالنسبة لحصة الفرد. ربع السكان لاجئون. مع دخول الأزمة السورية سنتها الثامنة ، استضاف لبنان حوالي 1.5 مليون لاجئ سوري. فرضت الأزمة قيودا كبيرة على الخدمات العامة ، حيث تجاوزت الاحتياجات بكثير قدرة المؤسسات والبنية التحتية.

يتميز قطاع المياه ومياه الصرف في لبنان بأدوار ومسؤوليات غير موضحة ذات وظائف متداخلة. الإدارة السليمة لمياه الصرف هي قضية وطنية، ومع التدفق السريع للاجئين وخيارات الصرف الصحي المحدودة، تشكل الظروف في مخيمات اللاجئين تحديا خاصا.

يركز هذا البحث على مخيمين للاجئين في بر الياس ، وسهل البقاع ، لبنان ، والذي يستضيف في الوقت الحالي 2200 شخص تقريبا. يتشكل الحل الحالي لمياه الصرف والصرف الصحي دُشات عائلية داخل كل مأوى. يتم توصيل كل منزل بشبكة مياه في المخيمات من مراحيض و الصرف الصحي مع فصل المياه الرمادية (الاستحمام ، والمغاسل ، وغسل الصحون والملابس) والمياه السوداء (المرحاض). يتم تخزين المياه الرمادية في خزان للصرف الصحي مكون من غرفتين ويتم ضخه في خندق لري التربة قبل تصريفه في قناة الري القريبة. يتم تخزين المياه السوداء في خزان احتجاز ، ويتم ضخها في كثير من الأحيان عن طريق شاحنات نقل المياه. تقوم الشاحنات بجمع المحتوى ونقله إلى محطة معالجة مياه الصرف الصحي الكبيرة ، وهذا إجراء مكلف.

كان نوع التربة في المنطقة عبارة عن تربة ذات حبيبات دقيقة من الطمي والصلصال ذات قدر ة هيدروليكية محدودة. كانت تيارات مياه الصرف المختلفة الناتجة من المخيمات منخفضة جدا، ومن ثم كانت النتيجة المختبرية للمياه الرمادية عالية التركيز. لم يكن أداء معالجة المياه الرمادية في الموقع هو الأمثل ، ويجب تغيير تصميم نظام التسريب. يمكن القيام بذلك عن طريق إضافة طبقة من الرمل بين التربة الطبيعية والحصى الذي يحمل أنابيب التسريب، وإنشاء نظام التل. وتصبح النتيجة هي ارتفاع جودة النفايات السائلة ، ويمكن تصريف المياه الرمادية المعالجة في قناة الري دون التسبب في التلوث. لتوفير المياه ، يجب إعادة استخدام المياه الرمادية المعالجة بشكل مثالي لأغراض التنظيف أو البستنة أو غسيل الملابس.

يجب معالجة كلا من المياه الرمادية والسوداء في الموقع في نظام معقد لتحقيق إدار ة أكثر

استدامة وإعادة استخدام المزيد من موارد مياه الصرف الصحي في الموقع. إن تنفيذ تقنيات جديدة مثل المفاعلات اللاهوائية المانعة متبوعة بالمرشحات اللاهوائية أو اختياريا مجرد أغطية الحمأة اللاهوائية المتدفقة التي ستمكّن من توفير الغاز الحيوي كمصدر للطاقة. يمكن أن يزداد الغاز الحيوي المحتمل عن طريق إضافة النفايات العضوية (فضلات الطعام، وفضلات الحيوانات وما إلى ذلك) ، وإذا تم تركيب مراحيض تحويل البول لجمع البول بشكل منفصل. يمكن استخدام البول كأسمدة سائلة، بينما يمكن استخدام البراز كتعديل للتربة أو سماد في الحقول بعد أن يتم تصريفه في أحواض تجفيف الحمأة. هناك خيار آخر هو تركيب محطات معالجة مياه الصرف الصحي الصغيرة النقالة في المخيمات. هذه الحلول مناسبة في مخيمات اللاجئين المؤقتة لأنها فعالة ويمكن نقلها بسهولة إلى أي مكان.

كان اللاجئون عمومًا منفتحون جدا ومتجاوبين مع التغيير. كانوا جميعا مقتنعين بأنه إذا كان الحل الأكثر استدامة سيفيدهم، فينبغي تنفيذه. يتلقى اللاجئون تدريبا على الإدارة الذاتية لمرافق المخيم، ويشاركون في دروس حول المياه والصرف الصحي والنظافة الصحية. يوصي هذا البحث بمزيد من التفاعل مع اللاجئين لتنمية الأفكار وتحديد قدرتهم على المضي قدماً والحصول على نظام دعم ذاتي. يعد قبول السكان المحليين عاملاً رئيسياً لمشروع ناجح نظرًا لأنهم أصحاب القرار النهائي.

**كلمات الأساسية:** *لبنان، ومعالجة المياه العادمة، فصل المياه الرمادية ,والمياه السوداء، والتخلص من الفضلات البشرية، ومخيمات اللاجئين والصرف الصحي المستدام.*

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AF | Anaerobic filter |
| ABR | Anaerobic baffled reactor |
| BOD | Biochemical oxygen demand |
| BW | Blackwater |
| COD | Chemical oxygen demand |
| CFU | Colony-forming-unit |
| FGD | Focus group discussion |
| GW | Greywater |
| IOCC | International Orthodox Christian Charities |
| LCRP | Lebanon Crisis Response Plan |
| m.a.s.l | Meters above sea level |
| NGO | Non-governmental organization |
| NCA | Norwegian Church Aid |
| NMBU | Norwegian University of Life Sciences |
| TSS | Total Suspended Solids |
| UASB | Upflow sludge blanket |
| (u)PVC | (unplasticized) Polyvinyl chloride |
| URDA | Union of Relief and Development Associations |
| UN | United Nations |
| UNHCR | United Nations High Commissioner for Refugees |
| UNICEF | United Nations Children's Fund |
| WASH | Water, Sanitation and Hygiene |
| WHO | World Health Organization |
| WWTP | Wastewater treatment plant |

# 1. INTRODUCTION

Universal safe access to adequate water, sanitation and hygiene (WASH) is a fundamental need and a human right. Such facilities we take for granted in most developed countries, although modern sanitation is quite a new phenomenon.

According to the World Health Organization (WHO & UN-Water, 2017), 2.4 billion people lack basic sanitation services which is a major cause of illnesses, epidemics and early death. When it comes to Lebanon today, although in ancient time part of a highly advanced developed culture, water- and sanitation facilities are often inadequate.

With the rapid influx of refugees and already constrained water- and sanitation facilities, conditions in the refugee camps are especially challenging. Implementing well-designed sanitation solutions is important in order to assure good health in the refugee population and to improve their quality of life. However, the constraints of time, resources and space during emergency situations, usually leads to the use of standard remedies and not optimum solutions that may prove to be more effective in the medium- and long-term.

The aim of this study is to evaluate the wastewater- and sanitation system in Yasmine and Awda informal settlements, located in Bar Elias, Bekaa Valley, Lebanon. Furthermore, this thesis will propose solutions to improve the present solution and provide good living conditions within the refugee camps. The methods utilized include interviews and discussions with the refugees, NGOs and other WASH experts, in addition to field tests and observations at site. The studied camps were established in 2014 and 2016 and host around 2200 refugees in total today, mostly people who have fled from the Syrian crisis.

## 1.1 MAIN OBJECTIVE AND RESEARCH QUESTIONS

The two main objectives of this study are (1) to evaluate the existing sanitation system and (2) propose possible improvements that could be implemented at site.

In the search to fulfill the objectives of this study, the following specific research questions were further investigated:

- How does the existing wastewater and sanitation system function?
- What would be a more sustainable solution in these refugee camps?
- What kind of solutions is adaptable according to the local conditions?
- What are the possibilities for reuse and wastewater treatment on-site?
- Are the refugees satisfied with the present solution?
- How would the refugees respond to changes and implementation of new solutions?

## 2. BACKGROUND INFORMATION

This chapter will present necessary information to understand the general context and relevance of this study. Lebanon's country profile will be presented, including the institutional framework, policies and strategies and wastewater management in the country. In addition to the impact of the Syrian crisis. Furthermore, this chapter include a description of wastewater management in refugee camps in general, and the situation at the studied camps will be presented at last.

### 2.1 CURRENT SITUATION IN LEBANON

#### 2.1.1 COUNTRY PROFILE

Lebanon is located along the eastern coast of the Mediterranean Sea. The total area is 10.452 km$^2$ (CAS., 2019) **Figure 2.1** illustrate that the population in Lebanon has increased intensely especially since the Syrian crisis. Between 2011 and 2018 the population increased by approximately 30 per cent, to a total of about 6.1 million people today. The population density in Lebanon is 596 people per km$^2$ (UN, 2018).

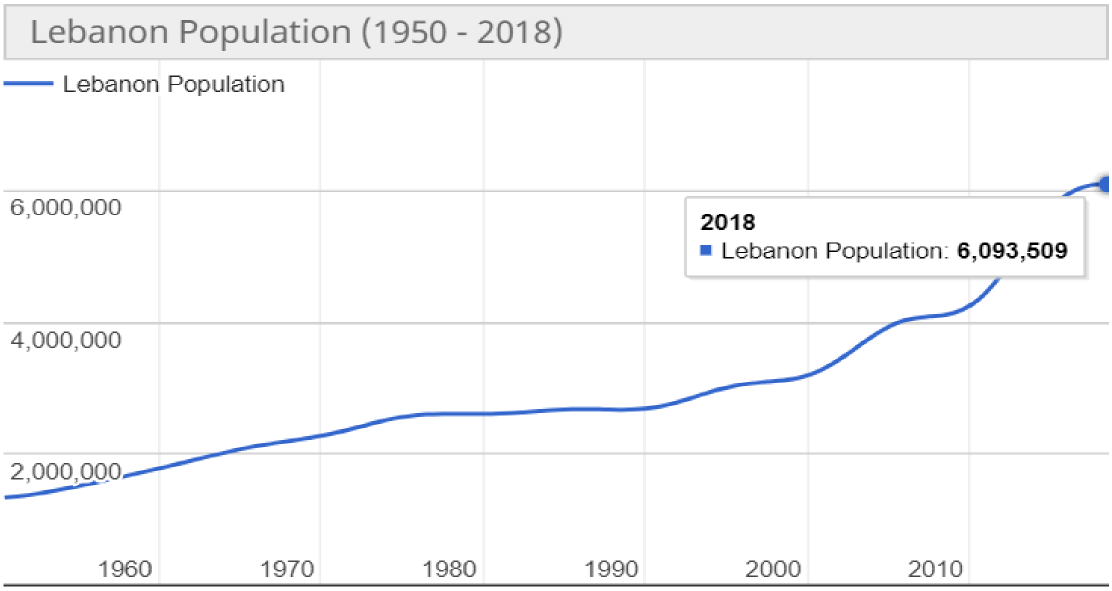



Figure 2.1: Population of Lebanon 1950-2018 (UN, 2018). The Syrian crisis erupted in 2011.

**Geographically,** Lebanon is dominated by two mountain ranges, the costal range (Mount Lebanon) and the inner range (Anti Lebanon). The Bekaa plain lies between them and represent the main agriculture resource of the country, with large areas with fertile soil for crops such as fruit and olive trees, cereals, vines and vegetables (Darwish et al., 2008). The country consists of 300-360 thousand hectares arable land, and between 67-100 thousand hectares of them are currently under irrigation. The urban expansion has increased in the last decades, and so has the pressure on limited soil and water resources and the risk of groundwater contamination (Steinel & Margane, 2011).

**Geologically,** Lebanon is mostly built up of a thick sedimentary sequence from Jurassic to recent time. The country represents a series of geomorphologic units ranging from level quaternary plains to steep and sloping mountains with alternating hard limestone rocks and soft marlstone. There is a variability in landforms, climate and mineral substrates, and the soil types varies from Fluvisols, Vertisols, Cambisols, Luvisols, Leptosols, Calcisols and Regosols (Darwish et al., 2005).

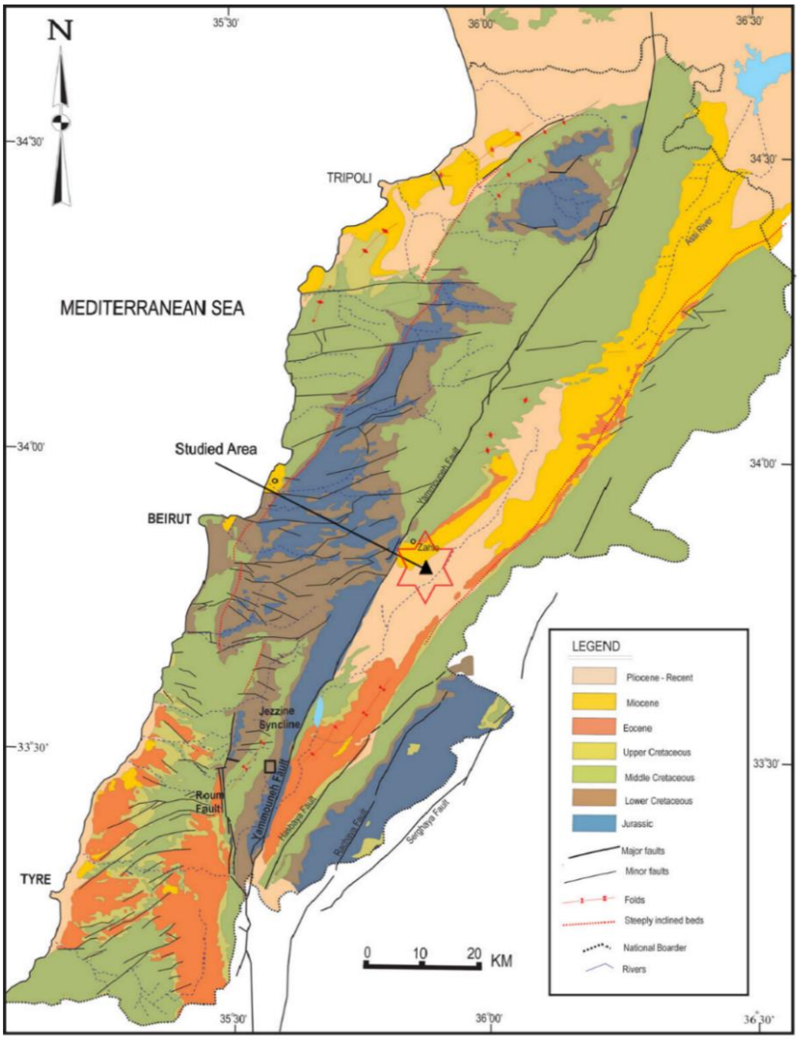



Figure 2.2: Overview of geological structures in Lebanon with the studied area marked with a star (After: Walley, 1998)

**Climatically,** Lebanon has Mediterranean climate characterized by cold, rainy winters, and long, hot and dry summers. The small country consists of various geographical zones with wide differences in climate. Bekaa Valley is in the rain shadow of Mount Lebanon, and the result is considerably less precipitation and humidity, and a wider variation in daily and yearly temperatures in this area. The mean precipitation in the coastal strip of Lebanon is around 2000 mm/year, compared to Bekaa Valley with only one-tenth as much (Brooks, 2007).

**Hydrologically,** Lebanon has about 40 streams, but less than half of them are flowing the whole year around, whereas the others are just seasonal. Most of the rivers originate from karst springs on the western slopes of Mount Lebanon and flows towards the Mediterranean Sea. The Litani River is the longest river (170 km), and it rises in the fertile Bekaa Valley, and empties into the Mediterranean Sea North of Tyre. The average flow is estimated to be around 920 million $m^3$/year, and the river provides a major source for irrigation, water supply and hydroelectricity in the south of Lebanon, and the country as a whole (Steinel & Margane, 2011).

### 2.1.2 WASTEWATER MANAGEMENT IN LEBANON

As a result of years of political instability, disintegrated state structure responsibilities within the sector and poor planning, wastewater management in Lebanon is insufficient and covers only a small proportion of the population. During the civil war period (1975-1990) there was an absence of institutional control of public authorities and many of the existing wastewater treatment plants were destroyed and made inoperative. A large amount of domestic wastewater is still discharged directly into the recipient, with no treatment prior to disposal (Karaa et al., 2005).

Approximately two-thirds of the population is connected to sewer networks, but only eight per cent of this amount reaches an operational wastewater treatment plant. The environmental costs of this situation are severe. Wastewater management is a national issue, and the use of septic tanks and other primitive sewage disposal methods are widely spread (Karaa et al., 2005).

To achieve properly wastewater treatment and management in Lebanon is prioritized. The government, through its ministries (MoEW, MoE, Municipalities and CDR), has numerous projects underway to construct large- and medium-sized wastewater treatment plants. However, because of the technical complexity and financially expensive construction, it is my understanding that more distant communities and villages cannot afford to implement large conventional centralized treatment systems. Therefore, simple, sustainable and economically affordable treatment systems should be adopted in these areas, e.g. small-scale wastewater treatment plants and ecological sanitation systems.

Due to the lack of proper treatment, only a limited extent of wastewater reuse is practiced in Lebanon. Urban expansion, intensive agriculture and industrial activity have been increasingly stressing the limited soil and water resources (Darwish et al., 2008). The agricultural sector has the highest potential for reuse as this sector accrues up to 70 per cent of the total water demand (Steinel & Margane, 2011). Greywater and excreta contain water and nutrients, which make them valuable resources, and the reuse of them will reduce the need for artificial fertilizers and would be important for nutrient recycling (WHO, 2006). Table 2.1 represent the Lebanese guideline for wastewater reuse.

Table 2.1: Lebanese guideline for wastewater reuse (FAO, 2010a)

| Class | I | II | III |
|---|---|---|---|
| Restrictions | Produce eaten cooked; irrigation of greens with public access | Fruit trees, irrigation of greens with limited public access | Cereals, oil plants, fiber and seed crops, fruit trees and industrial crops and areas of forest without public access |
| $BOD_5$ mg $O_2$/L | 25 | 100 | 100 |
| COD mg $O_2$/L | 125 | 250 | 250 |
| TSS mg/L | 60 | 200 | 200 |
| pH | 6-9 | 6-9 | 6-9 |
| Residual $Cl_2$ mg/L | 0.5-2 | 0.5 | 0.5 |
| $NO_3$-N mg/L | 30 | 30 | 30 |
| Fecal coliforms (/100 mL) | <200 | <1000 | None required |

### 2.1.3 INSTITUTIONAL FRAMEWORK, POLICIES AND STRATEGIES

There is a range of different municipalities, authorities and ministries responsible for the water- and wastewater sector in Lebanon today. The roles and responsibilities are not entirely clarified and overlapping functions is a challenge. Therefore, structural reforms are required to make the sector more self-sustaining and efficient, that is to have viable tariff and financial scheme, and to establish an adequate regulatory framework (Steinel & Margane, 2011).

The main agencies for the water- and wastewater sector are the following:

- Ministry Energy and Water (MoEW): Responsible to develop the National Water Sector Strategy and works as a supervisor for LRA and RWE. MoEW develops a legal framework and procedures to protect water resources from pollution and improve the water quality.
    - Litani River Authority (LRA): Management of water resources, mainly measure the amount of surface water and groundwater and monitor the water quality in the Litani River basin.
    - Regional Water Establishments (RWE): Law 221/2000 established four Regional Water Establishments in Lebanon (Bekaa, North, South and Mount Lebanon), which are responsible for the operation and maintenance of water systems, water supply and wastewater treatment in their region.
- Municipalities (under the Ministry of the Interior): Provision of water- and sewer networks and building and maintenance of infrastructure, in addition to collect water fees. In some cases, they overlap with the RWE for the operation and maintenance of the water systems.
- Council for Development and Reconstruction (CDR): Implementation of priority reconstructions and development of many large-scale wastewater projects.
- Ministry of Environment (MoE): Formulate a general environmental policy, and monitor and establish environmental standards. Influence the planning of land use; protection of biodiversity and control the pollution.
- Ministry of public health (MoPW): Ensure water quality and safety; epidemiological surveillance.
- Ministry of Agriculture (MoA): Development of irrigation projects and management of natural resources.

The main regulations and guidelines directly related to wastewater management are the following:

- Decree 8735/1974 on pollution from solid waste and wastewater
- Decision 52/1: Standards and limits for air, water and soil pollution (MoE, 29/7/1996)
- Decision 8/1: Standards and the emission limit values for wastewater discharge into the sea, surface water or sewer networks (Table 79, MoE, 30/1/2001)
- Decision 3/1 on environmental guidelines for establishment and operation of small-scale WWTPs
- The National Water Sector Strategy (MoEW, 2010-2020)
- WHO guidelines for safe use of wastewater, excreta and greywater (WHO, 2006)
- United Nations' Sustainable Development Goals, SDG 6: "Ensure availability and sustainable management of water and sanitation for all" (UN, 2015)

The Lebanon Crisis Response Plan (LCRP) is a multi-year plan between the Government of Lebanon (GoL) and the humanitarian community (United Nations (UNHCR), international and national NGOs and donors). They share responsibility for the crisis, and the plan provides a stabilization and humanitarian framework to tackle Lebanon's challenges holistically, considering the vulnerability of all people affected by this.

### 2.1.4 THE SYRIAN CRISIS

As the Syrian crisis enters the eighth year, Lebanon remains at the forefront of one of the worst humanitarian crises of our time. Over this period, Lebanon has been a host to almost 1.5 million Syrian refugees, cf. Figure 2.3. In addition to hosting 35.000 Lebanese returnees, a pre-existing population of more than 180.000 Palestine Refugees in Lebanon (PRL) and 28.800 Palestine Refugees from Syria (PRS). This is the fourth largest refugee population in the world, and the largest concentration of refugees per capita (GoL. & UN., 2019). Approximately one-third of the refugees in Lebanon are settled down in the Bekaa region where this study is conducted.

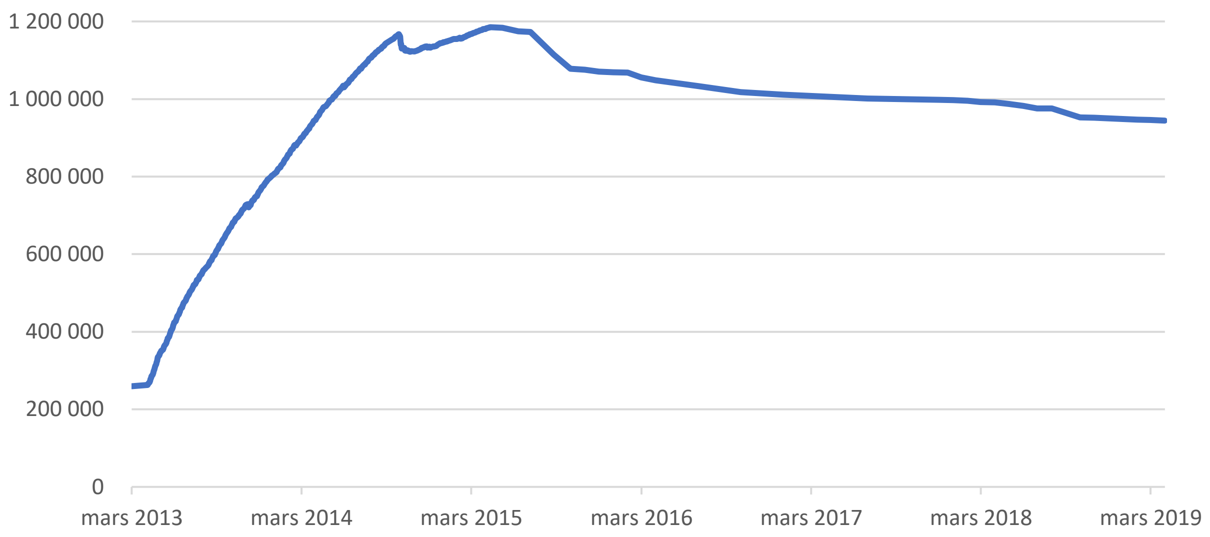



Figure 2.3: Registered Syrian refugees by date (Data from: UNHCR, 2019)

With the rapid influx of refugees and already constrained water- and sanitation options, the conditions in the refugee camps are especially challenging. The public services are overstretched with demands far exceeding the capacity of institutions and infrastructure to meet the needs. The Government of Lebanon, aid donors and humanitarian actors have obligations under United Nations' SDG 6 to ensure the availability and sustainable management of water and sanitation for all. This is not possible without more international aid in order to sustain the population in the long-term that meet the needs of refugees and the Lebanese communities that hosts them (GoL. & UN., 2019).

### 2.1.5 WASTEWATER MANAGEMENT IN REFUGEE CAMPS

The government of Lebanon has prohibited international organizations from establishing formal refugee camps or any permanent infrastructure. This means that nearly all the refugees are self-settled and live in apartments, abandoned buildings or informal settlements, mostly dispersed in the major cities and in Bekaa Valley, near the Syrian border. This decision will not allow them to be connected to municipal water- or sewage networks, thus contracted services such as water trucking and desludging with pump trucks are common.

The refugees in Lebanon have different living conditions, and hence the access to sanitation facilities varies. In a refugee camps, two different phases may occur; the emergency phase and the stabilization phase. The first phase refers to relief operations where quick solutions are selected to satisfy the most essential needs. To build a simple pit latrine, a shallow trench latrine or a defecation field could be a solution for human excreta disposal in this phase. The second phase occurs once the situation is perceived as a non-temporary. The temporary solutions are improved or replaced by more complex constructions, e.g. construction of pipe networks connected to one improved toilet per household (Davis & Lambert, 2002).

After so many years, the context in the refugee camps in Lebanon has changed from emergency to stabilization phase, but the availability and sustainable management of water and sanitation for all, are still not fulfilled (UNHCR., 2007). Figure 2.4 illustrate the access Syrian refugees had to sanitation facilities across shelter types in 2017. The refugees who lived in residential shelters, compared to non-permanent shelters, had better living conditions and access to more improved sanitation facilities. This kind of facilities could be improved toilets or latrines, which are not shared, and where the excreta are safely disposed of or treated off-site. 44 per cent of the displaced Syrians living in informal settlements had access to basic services only (non-residential shelters: 63 %, residential shelters: 77 %). In total, 68 per cent of the refugees had access to basic sanitation service, and 87 per cent had access to improved sanitation facilities (UNICEF et al., 2018).

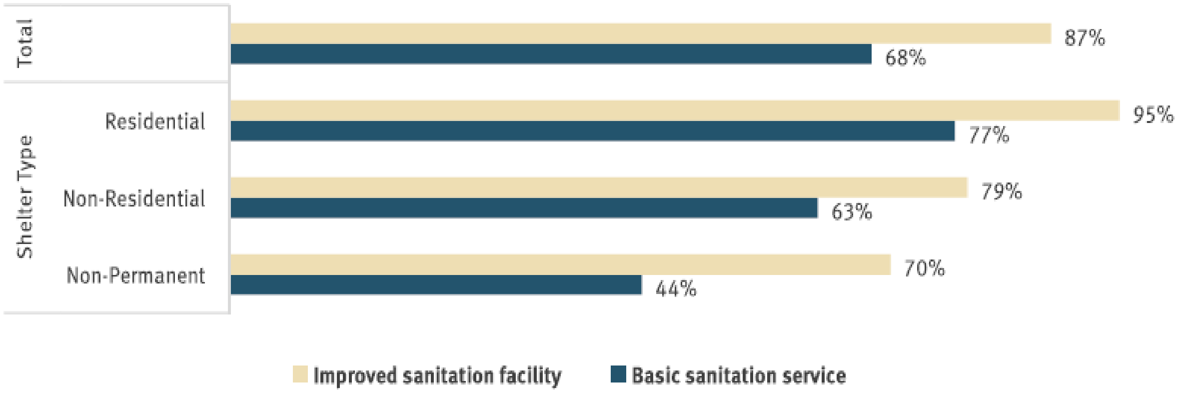



Figure 2.4: Share of households using improved sanitation facilities across shelter types (VASyr, 2018)

## 2.2 YASMINE AND AWDA INFORMAL SETTLEMENTS

This study will evaluate the wastewater- and sanitation system in Yasmine and Awda informal settlements and propose possible improvements that could be implemented at site.

The camps are situated in Bar Elias, Bekaa Valley, Lebanon. Measurements by a hand-held GPS gave the following coordinates:

-33°47'34''N 35°56'03''E *(Awda camp)* -
33°47'47.9"N, 35°56'11.0"E *(Yasmine camp)*

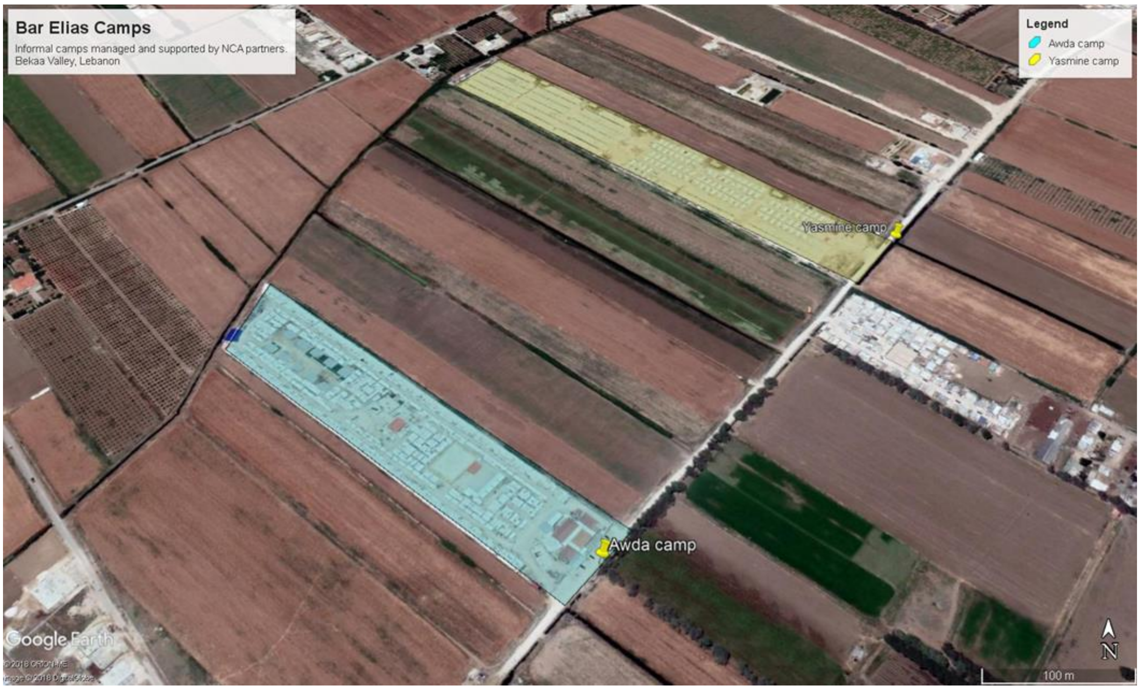



Figure 2.5: Location of Yasmine and Awda informal settlements (Google Maps, 2018)

### 2.2.1 GENERAL INFORMATION ABOUT THE CAMPS

The camps are being governed by the local organization Union of Relief and Development Associations (URDA) on municipally owned land. Yasmine and Awda refugee camps where initially established in 2016 and 2014, in coordination with the Lebanese Ministry of Interior (Municipalities) and the UN Refugee Agency (UNHCR).

The refugee camps work as small independent communities, including school, playground, mosque, clinic and restaurants on the inside. There are also several small shops selling almost everything the people need, e.g. groceries, fruit and vegetables, toys, electronical devices and other utilities.

There are currently 317 households in Yasmine camp and 342 households in Awda camp, and the refugees reside in either one-room caravans, tents or reinforced cement-block shelters. Some of the dwellings are elevated above ground level or built on a concrete slab, and they will be less exposed for flooding. Inside each dwelling the families have space for a small kitchen, bathroom and living-/bedroom.


Figure 2.6: Different types of dwellings in the refugee camps

International Orthodox Christian Charities (IOCC) have provided WASH-support to both camps, under a Norwegian Church Aid (NCA) program, and this included an upgrade of the water- and sanitation network, separation of grey- and blackwater, installation of septic- and holding tanks, arranging of water trucking and desludging services and hygiene promotion. After the hand-over of the project, IOCC continued to support the water trucking and desludging services costs. Other costs are supported by the refugee's monthly payment and URDA's external partners (OXFAM, governments of Qatar and Kuwait).

**Table 2.2** compare the minimum standards for people to survive (emergency phase) and recover (stabilization phase) according to the Sphere Handbook (Sphere Association, 2018), with the conditions in Yasmine and Awda informal settlements.

Table 2.2: Conditions in the camps compared to recommendations from the Sphere Handbook

| Indicator | Unit | Emergency phase | Stabilization phase | Yasmine camp | Awda camp |
|---|---|---|---|---|---|
| Water consumption | L/pe/day | ≥15 | ≥20 | ≥40[1] | ≥40[1] |
| Distance to water source | Meters | ≤500 | ≤200 | <500 | <500 |
| People per toilet | # of people | ≤50 | ≤20[2] | 1 toilet per household | 1 toilet per household |
| Distance to toilet | Meters | <50 | <50 | 0 | 0 |
| Households with access to toilets | Per cent | ≥60 | ≥85 | 100 | 100 |

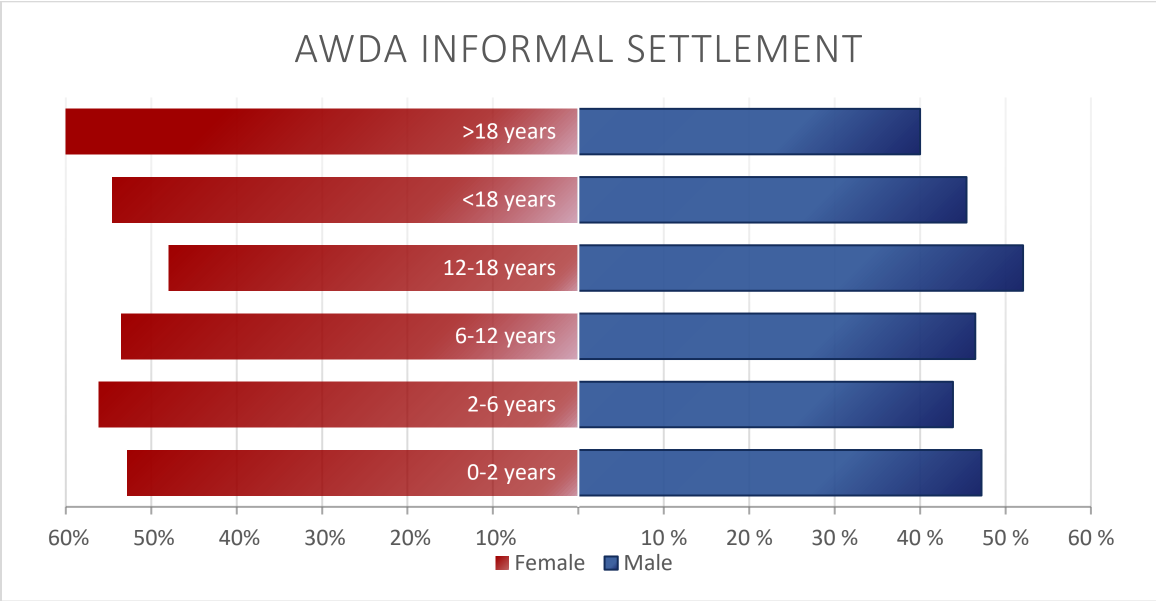
Note: [1][Total water consumption (drinking water, shower, washing, flushing from trucked water sources], [2][The goal is 1 toilet per household]

### 2.2.2 DEMOGRAPHIC INFORMATION

Registration data from the end of January until the beginning of March 2019 was collected at site. After the strong windstorms "Norma" and "Miriam" that caused damages to infrastructure, roads and homes across the country this winter, the population in the studied increased to approximately 1059 people in Yasmine camp and 1128 people in Awda camp. Around 100 families settled down in Yasmine informal settlement because their tents had collapsed due the extreme whether with strong wind, heavy rain and snow, and very low temperature for many days. The affected people settled down for a short-term only, which made it challenging to identify their needs caused by the destruction flood.

In April 2019, there were 515 people registered in Yasmine camp, and 1061 people registered in Awda camp. There was a slightly excess of woman and girls, and more than half of its population was under the age of 18.

The demographic data is represented in **Figure 2.7** below.



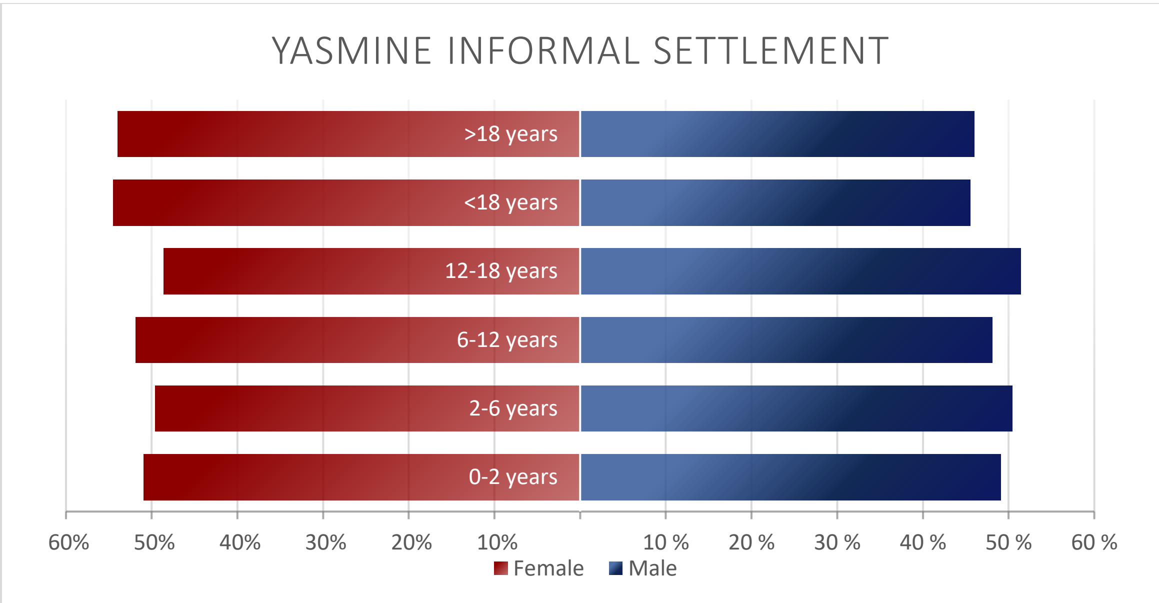




Figure 2.7: Demographic information in Yasmine (515 people) and Awda (1061 people) informal settlements

The education system in Lebanon is divided into 5 cycles in 3 phases: pre-school education, basic education and secondary education, the next stage is tertiary education, that is baccalaureate or professional certificate. Within the refugee camps, 71 per cent had an education level equivalent to basic education (grade 1 to 9), 13 per cent had secondary education (grade 10 to 12) and 16 per cent had finished tertiary education. For many years, the Syrian refugees have either worked in the construction-, craft or agricultural sector, but the majority of the people in the studied camps are today unemployed. They spend most of their time on the inside of the camps, and do not have much to do during the days. There is a lack of money, and they are dependent on external support from donors, such as food vouchers, that are provided to them occasionally.

### 2.2.3 SOCIAL AND CULTURAL ASPECTS

Most of the refugees have fled from the Syrian conflict, in addition to some refugees coming from Palestine. They come from different areas and from various social and cultural backgrounds. Some of them come from semi-urban areas and they often have a higher level of education, while others come from rural Bedouin ancestry, and have a very different background and social behavior. In my opinion, these differences should be addressed when individual needs and the approaches to provide services to the refugees are made. If sanitation improvements are to be widely accepted, the relevant social and cultural factors must be taken into consideration during planning and implementation. It is important to understand how the society functions, including all the households within it, and what factors that promote change.

Many refugee camps in Lebanon are controlled by a "Chawich". This person has the political power or holds a socially dominant position and will make all the decisions on behalf of the refugee population. This include whom shall benefit from the water- and sanitation facilities, food supply and shelters. Their power and interests will often run in counter to the interests of individuals in the camp, and the people who are not close to the Chawich can become increasingly neglected and vulnerable. Yasmine and Awda informal settlements have no Chawich, and they are governed by URDA and operated in cooperation with their external partners. This could be a fairer solution in a camp setting, where the people should be treated with equal respect.

The refugees in Lebanon are seen as temporary visitors, which results in a short-term planning approach that may be maintained for years after their arrival. It is my understanding that it is important to encourage and enable the refugees to develop a sustainable life for themselves, even though it is hoped that this will only be a temporary solution. They may have lost their earlier jobs and belongings, but they are not incapable to organize themselves and create a new worthwhile life in the camp. Their skills and education are not gone, and they should be given the opportunity to redefine themselves within the context of the new community.

The refugees in the camps are selected on the basis of vulnerability, and therefore there is an excess of women and children. Women are often responsible for preparing food, cleaning, caring for children, the sick and the elderly and collecting water and cooking fuel. Most of them participate in different WASH-sessions, to learn good habits and they get the opportunity to express their own needs and concerns. Actively engaging women will probably help to ensure that all services are accessible to the refugees and this could encourage the population participate in the planning and decision-making processes. Helping them to help themselves should be the principle behind relief assistance; given responsibility for their own future, they are more likely to have hope in the future.

### 2.2.4 HYDROGEOLOGICAL CONDITIONS

The refugee camps are situated in Bekaa Valley, which represent the main agriculture resource of Lebanon, with large areas for fertile soil for different crops. Before the camps were built, the areas were used as a potato farm.

The main soil classes in the Bekaa plain are Regosols, Cambisols, Fluvisols and Vertisols, and they have often relatively deep profiles and could be of claylike or of sandy silt texture (Darwish et al., 2008). The soil type in the camps is reported down to at least 1.5 m, and is mainly clayey, silty and adhesive in nature. The soil seemed to be fairly well-sorted and fine-grained, c.f. Figure 2.8.

Figure 2.8: Soil profile next to the irrigation channel

Apparently, the groundwater level in the area could be relatively deep and is assumed to be more than 10 m below the ground in the camps, while the perched groundwater table is much shallower, about 1-1.5 m deep. This shallow table is likely in some degree to have hydraulic continuity and is possibly fed by the network of irrigation ditches and channels across the area. The water in the irrigation channels is widely reported to be contaminated with agrochemicals, nitrate, suspended solids and organic matter, as well as bacteria and other pathogens (Darwish et al., 2008). Ultimately, the water will end up in the Litani River, which lies about 1-2 km Northwest of the settlements.

### 2.2.5 PRESENT WASTEWATER- AND SANITATION SOLUTION

The rehabilitation and upgrade of the sanitation system was conducted by IOCC, and finished February 2018 in Yasmine camp, and March 2014 in Awda camp. The solution today is family toilets and showers inside each dwelling connected to a wastewater network with separation of greywater (shower, sink, dish- and clothes washing) and blackwater (toilets). Drinking water is stored in four large 10.000-liter tanks at the entrance of the settlements, and the refugees refill their jerry cans to collect water. The non-potable water is fetched from nearby shallow wells, stored in 10.000-liter tanks and pumped through the pipe network to distribute each household in their 1000-liter tanks.

Figure 2.9 (left): Girls that refill their jerry cans in one of the four drinking water tanks in Yasmine camp
Figure 2.9 (right): Each household is connected to the pipe network and the pumping line goes to their 1000-liter non-portable storage water tank

Many concrete manholes exist in the settlements, allowing easy access from all units, and ideal maintenance conditions in case of any blockages or damages of the pipes. The pipes cover long distances of low gradient land, and because the perched water table is high in the area, the drainage system is shallow. The pipe network in the camps reaches every household and station, and it is connected to different septic- and holding tanks of 24.5 m³ size (3.5x3.5x2 m) in plastered waterproofed concrete material.

-**The blackwater holding tanks** consist of one chamber without overflow, where the content is pumped out by vacuum tanker on a regular basis. This will happen through a flexible hose connected to a vacuum pump, which lifts the content in the tanker. The truck collects the content and transport it to either Zahlé or Joub Janine wastewater treatment plant.

-**The greywater septic tanks** consist of two chambers. Most of the solids should settle in the first chamber, and this will prevent solids and scum to escape with the effluent, in addition to reduce short-circuiting through the tanks. After pretreatment, the greywater is furthermore pumped to a soil infiltration trench Northwest in the end of the camps. The greywater infiltrates through the soil before discharge into the irrigation channel nearby.

The present wastewater- and sanitation system with separation of grey- and blackwater is illustrated in Figure 2.10.

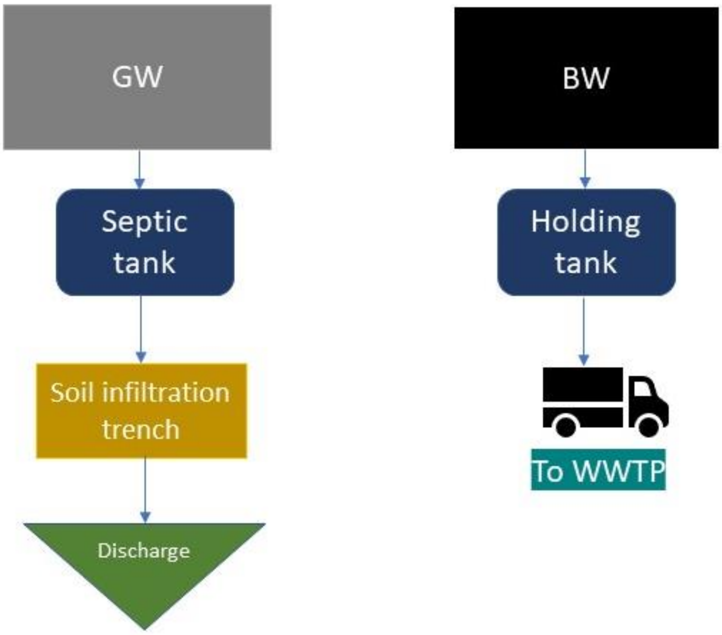



Figure 2.10: The present wastewater- and sanitation system in Yasmine and Awda informal settlements

The strengths, weaknesses, opportunities and threats for the present system taken up by this study is summarized in Table 2.3 below.

Table 2.3: SWOT-analysis of the existing situation

| | |
|---|---|
| Strengths | *The camps are properly planned with adequate infrastructure, and the access to water- and sanitation facilities fulfills the minimum standards according to the Sphere Handbook.* |
| Weaknesses | *There is no durable operation and maintenance plan, the solution is highly dependent on external funding to persist and the local organization have no knowledge and skills regarding wastewater and sanitation.* |
| Opportunities | *The refugees get training in self-management of the camp facilities, and have participatory learning about water, sanitation and hygiene. The refugees should create a committee and develop a system of administration which is self-supportive.* |
| Threats | *The solution today is not sustainable, and the access to the facilities could be in shortage due to population growth in the camps and lack of funding.* |

# 3. RESEARCH METHODOLOGY AND FIELDWORK

This chapter will discuss the methods used to answer the research questions, and the aim is to justify the methodological choices made in this study. The overall research approach and methods are described and discussed. The data collection tools will be discussed further in depth, and what findings this study are based on. Finally, the methodological strengths and weaknesses will be determined by evaluating the limitations and reliability behind the methods.

## 3.1 OVERALL RESEARCH APPROACH AND METHODS

The overall research method of this study was twofold; part one consists of data collected through interviews and discussions with the refugees, NGOs and others. The aim was to assess how the existing system worked and to consider the social implication of introducing a new solution in the camps. Part two consists of the data collected from field tests and observations at site, to make a hydrogeologic assessment of the area. The purpose was to consider the local conditions and be able to suggest an improved solution.

## 3.2 CHOICE OF RESEARCH DESIGN

This study was dependent on both primary and secondary sources of data collection, and both qualitative and quantitative methods were used to complete the research. Strengths in using mixed methods are that it could help the researcher to develop a more complex picture of the case, that include both trends and individual's experiences, in addition to quantifications and measurements.

Primary data was collected from sources such as personal interviews, field tests at site and observations, while secondary data was collected from governmental documents and regulations, journal articles, books, reports by local and international organizations, sanitation compendiums and construction manuals. The secondary data were needed to achieve additional insight and comprehension, and to provide supplementary background information surrounding the topics.

## 3.3 DATA COLLECTING TOOLS

The data collection was carried out from the 27th of January 2019 until the 3rd of March 2019. To assess the wastewater- and sanitation situation in Yasmine and Awda informal settlements, and the possibility for improvements from different angels in a wider context, data was collected in several ways as described in the following sections.

### 3.3.1 LITERATURE REVIEW

An in-depth literature research was conducted to begin with, covering topics related to research methodologies, wastewater management in refugee camps, Lebanon and the Syrian crisis, wastewater management in Lebanon and sustainable sanitation solutions. The used resources for this study include books, governmental documents and regulations, journal articles, reports by local and international organizations, sanitation compendiums and construction manuals.

### 3.3.2 MEETINGS WITH THE LOCAL ORGANIZATION, NGOS AND OTHER WASH EXPERTS

The local organization URDA gave important information that helped to analyze the population profile and to find the background context of the situation. This included demographical data, a description of the population and their different earlier occupation, education level, economic conditions, health and diseases, religion and culture. Meetings with other key persons involved in the project was arranged to get useful background data for Yasmine and Awda informal settlements and how the situation in the camps has developed today.

WASH-experts like UNICEF, Orenco® Systems, Biorock® Wastewater Treatment, and local companies like cubeX and Difaf, were contacted to discuss possible solutions based on the suitability at site, Lebanese standards and regulations and to give their personal advices and experiences from other similar projects.

The time schedule and list of meetings could be found in Appendix I.

### 3.3.3 SEMI-STRUCTURED INTERVIEWS WITH LOCAL HOUSEHOLDS

Semi-structured interview is a standard investigate approach in a qualitative research and was carried out to better understand the local households' practices, preferences and awareness surrounding the wastewater- and sanitation situation. A questionnaire with 18 questions was used, and each interview took about 15-30 minutes. The purpose was to find out what the households thought about the present water- and sanitation system and how they would respond to a change, and the opportunity to make a more sustainable system.

The interview was held in Arabic and translated to English by an interpreter. Each interview followed a guideline procedure were I first introduced myself and explained the purpose of the interview. In adherence to ethical standards, the respondents were assured that their participation was voluntary, that the information they provided would be used for academic purposes only and that they would remain anonymous. The selected respondents would not experience any negative consequences, and the rights for privacy was uphold both during and after this survey.

The first section was about demographic information and the respondent's social economic status (name, age, gender, education level and occupation). Afterwards the respondents were asked about their household characteristics (householder members, number of children and adults). The main section was about sanitation, and the respondents were asked both simple yes/no questions and some open-ended questions. Opposed to closed-ended questions, open-ended questions will help the researcher to get a deeper perspective and the respondent's feelings about the topic. The respondents were sometimes asked follow-up questions to prove and pursue interesting responses. The last section was about their willingness and openness to try a new, more sustainable solution. Different examples of ecological sanitation systems were explained, and the respondents were shown some illustrative pictures and movies. In the end of the interview the respondents were kindly asked to show their toilet and I took some pictures and notes about the available facilities and other observations.

A total of 21, out of 92 currently occupied households, were randomly selected and visited at Yasmine informal settlement. The distribution of men and women was 52.4 % and 47.6 % respectively, and the age of the respondents ranged from 14 to 70 years. Appendix II represent the demographic information of the interview respondents.

The questionnaire used in this survey could be found in Appendix III.

### 3.3.4 FOCUS GROUP DISCUSSION

Focus group discussions were carried out to get an idea of the diversity of thoughts on the different topics, and to get the refugees more involved in the decision-making processes.

The focus group discussions started with an introduction, where I presented myself and the purpose of this research. All the participants were thanked to take part of this study, and they were encouraged to share their opinions as an important part of the research.

The discussions were conducted in Arabic, and continuously translated to English. The first FGD was with a total of 10 men from 23 to 70 years old, and the second FGD was with a total of 30 women from 16 to 63 years old. They were first told to discuss the advantages and disadvantages of the present wastewater- and sanitation system. Afterwards, they were asked to discuss if the system needed to be upgraded, and in that case; how and why. In the last section, pictures of different sustainable sanitation solutions were showed, and they were asked to assess which one of them that will cover their biggest need and desire.

Option 1 could provide electricity to the refugees, and the participants were explained how they easily could collect urine to produce energy from microbial fuel cells or produce biogas from the sludge in a larger-scale system. The energy could potentially be used to light up toilets, charge phones, cook or heat up the household. Option 2 focused on the use of human excreta as a resource, and to reuse it as a fertilizer on crops or plants. Different source-separating methods were explained, and especially the principle behind urine diversion- and vermicomposting toilets. Option 3 focused on how they could save water, and the participants were explained how greywater could be reused after proper treatment for flushing, gardening purposes or laundry washing.

The topic guide for the focus group discussion could be found in Appendix IV.

### 3.3.5 PARTICIPANT OBSERVANT

Whereas conversations can give information on what the respondents may be thinking, observation will give information on what they do in practice. Participant observation is a method to gain firsthand experience of the research area, topic and community by living among and interacting with the people in their everyday life (Becker & Geer, 1957).

To support the findings in this study, I spent 3-4 days a week in Awda and Yasmine informal settlements and got the chance to observe the various aspects of people's everyday life and practices. In this way, I got the opportunity to get to know the people quite well and try to understand how they felt about their situation. During my stay, one thing that was surprising was the hospitality and openness of the people. Although most of them were living in extreme difficult life situations, they offered so much geniality and appreciation to be a part of this research. Most respondents were very grateful that someone was concerned about their issues and willing to hear about their challenges.

I attended several water, sanitation and hygiene sessions held by promotors from IOCC, and saw how the refugees engaged in the topics. One of the most important topics were hygiene promotion, where the refugees participated actively to learn good hygiene practices that promoted proper use and maintenance of the sanitation facilities in the camps.

Figure 3.1: Sessions and learning about water, sanitation and hygiene in the refugee camps ("How to properly wash your hands")

## 3.4 FIELDWORK AND HYDROGEOLOGIC ASSESSMENT

The hydrogeological situation in the area was assessed through a combination of different methods, including the study of scientific literature, field tests and observations at site. The following sections will further describe the different methods.

### 3.4.1 FIELD INVESTIGATION

A first systematic site visit with IOCC provided a general overview and first impression of the water- and sanitation system in the camps. To be able to suggest improved sanitation options, further investigations were assessed through infiltration tests, soil sampling and an analysis of the greywater.

Sampling- and infiltration sites were selected to be representative for the whole area, and they were located in close proximity to the soil infiltration trench in the Northwest end of Yasmine informal settlement.

The altitude and exact coordinates of the locations were determined by GPS, and they are presented in Table 3.1 below.

Table 3.1: Coordinates and altitude at site 1, 2 and 3

| | |
|---|---|
| Site 1: | 33°47'50.4"N, 35°56'06.1"E (876.2 m.a.s.l) |
| Site 2: | 33°47'50.4"N, 35°56'06.2"E (876.2 m.a.s.l) |
| Site 3: | 33°47'50.7"N, 35°56'06.3"E (875.8 m.a.s.l)<br>*-site for both soil sampling and infiltration test* |

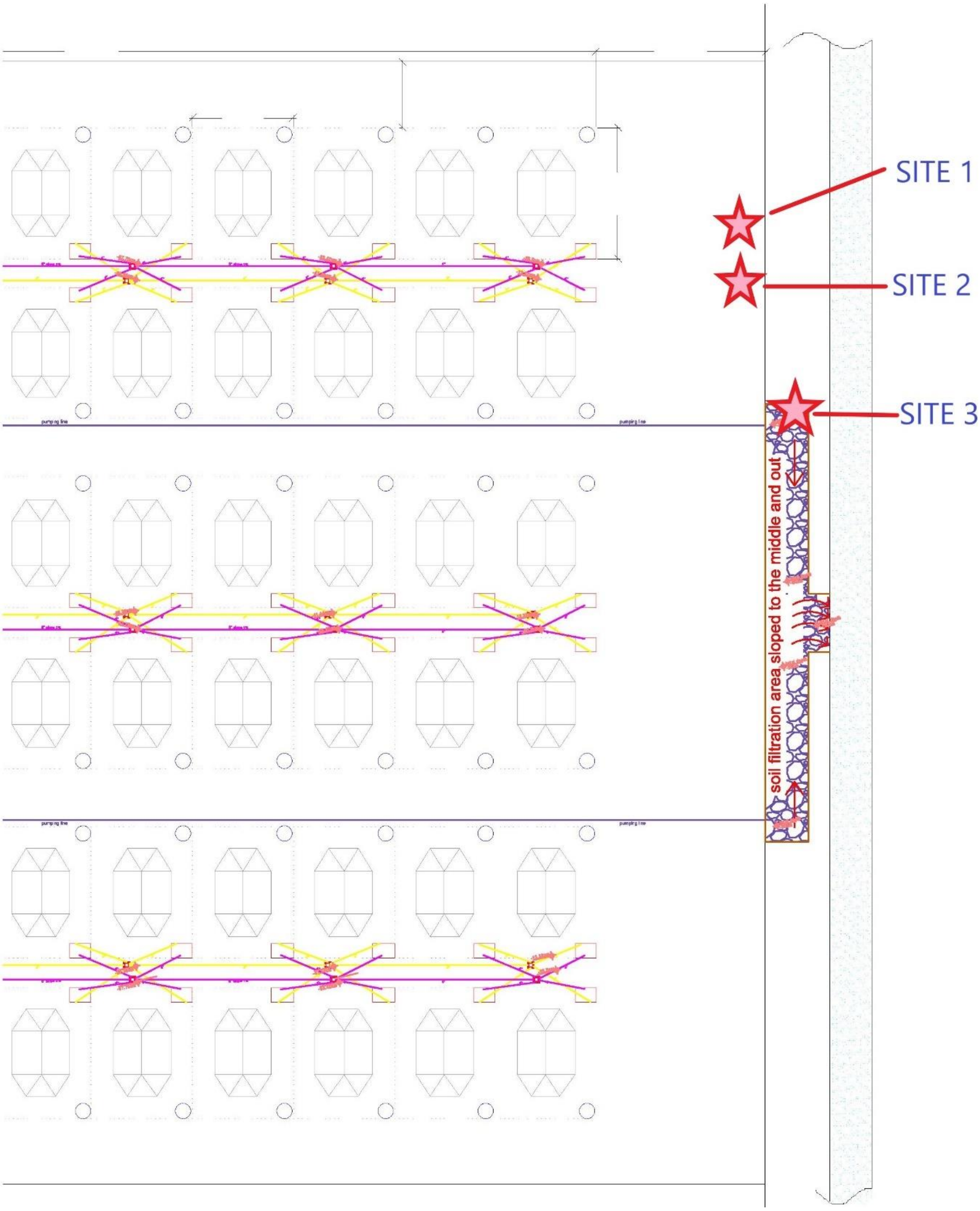



Figure 3.2: The three different sites in the Northwest end of Yasmine camp marked with a star

### 3.4.2 INFILTRATION TESTS

To determine the hydraulic conductivity, falling head pit infiltration tests were conducted at three different sites Northwest in the end of Yasmine camp. A falling head infiltration test is a simple method that does not require much equipment. The only devices used were a shovel to dig the pit, a bucket with water, a tape measure and a stopwatch to assess the infiltration rate.

The pit varied in size and was filled with a given amount of water as presented in Table 3.2.

Table 3.2: The different sites and sizes and initial water columns for the pits

| Site | Diameter [cm] | Depth [cm} | Initial water column [cm] | Volume of water [L] |
|---|---|---|---|---|
| 1 | 22 | 12 | 5 | 1 |
| 2 | 60 | 45 | 17 | 10 |
| 3 | 30 | 40 | 9 | 5 |

Figure 3.3: Site 1, 2 and 3 in the Northwest end of Yasmine camp

Once the pit was prepared, the soil surrounding the infiltration surface had to be saturated to allow the infiltration rate to stabilize before the tests. The pit was filled to the top with water, and the measurements started after the water had subsided to the bottom once. Without saturation first, the infiltration rate would be irregular; with rapid rate to begin with, and then getting slower as the soil pores would fill up.

The pits were filled with reasonably clear water, either fetched from the irrigation channel nearby or from the non-portable water tanks in the camp. For the first 10 minutes, the height was measured with a measure tape every single minute. Afterwards, time intervals of 5 or 10 minutes were used.

After the tests, all the data were plotted in Microsoft Office Excel with (1) the continuous drop in water level [cm] per unit time [min] and (2) the infiltration rate [cm/min] with the corresponding times [hr:min:s]. To calculate the infiltration rate, an interval for every 2 cm was used along with the corresponding times in each run.

In addition to the infiltration tests, a soil sample were brought to the laboratory for further investigation. The results from the laboratory and in the field were compared, to determine the hydraulic conductivity and suitability for infiltration in the area.

### 3.4.3 SOIL SAMPLING

A soil sample of 2.5 kilogram was taken from Yasmine camp at 40 cm depth. This sample was brought back to Norway and analyzed in the soil science lab at Norwegian University of Life Sciences (NMBU).

Figure 3.4: Soil sampling site (site 3)

The soil sample was dried for 48 hours at 105°C, to remove all the water before testing. The analysis in the laboratory gave basic physicochemical properties of the soil, like the pH, content of lime, and approximate soil texture and class. A sieve was used to separate between the particles over and under 2 mm in size. A detailed grain size distribution analysis was not performed because the major fractions were well-sorted and fine-grained silty clay.

Hydrochloric acid (HCl) was added to the largest particles to test if the sample contained calcium carbonate ($CaCO_3$). The reaction between HCl and $CaCO_3$ will cause effervescence.

The pH value was tested by adding deionized water to 10 mL of the soil sample, and then the value was calibrated in the pH measurement with two electrodes and buffer solutions of pH 4 and pH 7.

### 3.4.4 GREYWATER QUALITY ANALYSIS

Greywater contribute with the largest volume of wastewater from a household. In general, the concentrations of nutrients (phosphorous, potassium and nitrogen) and pathogens of health concern are low in greywater (Jenssen et al., 2004; Ottosson & Stenström, 2003), since most of them are found in the excreta. On the other hand, the microbial contamination of greywater is consequential, and must be considered when selecting treatment methods and calculating risks. When evaluating effluent disposal and sludge management, the appropriate treatment method should be based on different parameters.

A greywater sample was taken straight from the pipes in Yasmine camp on 11$^{th}$ and 18$^{th}$ of March and sent to the Lebanese Agricultural Research Institute (LARI) for analysis. The water quality is typically determined in terms of chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (DO), total suspended solids (TSS), temperature and pH. The Total Coliforms, Fecal Coliforms and Escherichia coli were tested with the standard ISO 9308-1:2000 methodology, and Total BOD and COD were tested with a purified kit from Hach-Lange.

## 3.5 RELIABILITY AND LIMITATIONS FOR THE RESEARCH

All gathered data has been organized and evaluated after the research period. This included the social aspect with interviews and focus group discussions, in addition to the measurements and field tests conducted at site. Obviously, all studies have potential for improvements and could be extended to include more aspects of its objectives. Financial aspects, time limitations and lack of human resources are common challenges and have also been for this study. Logistics and security issues were also something that needed to be addressed, as the environment and area around is known to be relatively tense. The main issue is with crime (in the Bekaa area in general, and especially near the Syrian borders), and smuggling and other types of crime often occurs. The security situation inside the camps was relatively safe, and the authorities was informed immediately if something bad happened. On April 24$^{th}$, 2019, a Lebanese Army force demolished 110 tents in Yasmine camp with bulldozers, claiming they were unoccupied and then arrested all the males residing in the camp. This incident caused anxiety, and all the families felt threatened to be homeless after this. A lot of the equipment and materials, including water tanks and sanitation facilities, were vandalized during the demolition. This incident showed a lot about the context and the challenges related with refugee settlements in Lebanon.

The interviews and focus group discussions with the local households reflects on a variety of opinions, values and personal experiences. Answers provided by the respondents may be influenced by temporary personal factors like mood, and situational factors like privacy and time pressure, and the topics could be uncomfortable to talk about for someone.

The conversations were conducted in Arabic, and then translated to English, and this could have opened for loss of important information. To avoid that the interpreter expressed the questions differently than intended, it was important to have a good dynamic, understanding and collaboration with the interpreter, and the aim of the research was explained with clarity. The participants were randomly selected in the camps, and the desire was to include all ages, elderly and children, as well as grown-ups, and an equal distribution of the sexes. A generalization of the findings is only possible to a certain extent, because it was not possible to include all the refugees, and this must be understood in the current context of this research.

The fieldwork was limited due to the lack of proper equipment, and the numbers of samples taken at site. The soil sample was taken from one location only. The ground was hard, and it was not possible to dig deeper than 60 cm manually with shovel. The soil type seemed uniform and the soil profile is therefore assumed to be fairly well-sorted.

Field infiltration tests at site will in general provide more accurate values of $K_{sat}$, but the used pit infiltration method may not be the most precise option among other in-situ tests. The unavailability of proper equipment was the main limiting factor determining this choice of method. The values from the measurements, only gave an indication of the saturated hydraulic conductivity, $K_{sat}$, and was higher than $K_{sat}$ because the water infilters in three dimensions from an open pit. More sophisticated instrumentations, for instance a Modified Philip Dune Infiltrometer or a Mariotte cylinder with a constant head infiltration, may have provided more accurate results.

To fully assess the on-site greywater treatment performance, one sample of the effluent should have been tested and compared to the sample analyzed in the laboratory. This sample was taken straight from the pipes, before receiving any treatment, and the tested parameters were only BOD, COD and bacteria. Other parameters should have been tested as well, to determine the microbial contamination in the greywater. I am concerned that the sampling of greywater could have been done incorrectly, and the tested COD and BOD values were even higher than expected normal strength for blackwater. There are many sources for error, and possible explanations could be that they used the wrong dilution factor at the laboratory or forgot to separate out the solids from the wastewater stream. There may also be practices within the households that are causing some of these high numbers, such as food scraps being put into the system, when they easily could be composted and used as fertilizer instead.

In general, the challenges and limitations did not make a significant obstacle for conducting the study as it was intended.

# 4. RESULTS AND DISCUSSION

This chapter will present the findings from the interviews and discussions with the refugees, in addition to the primary research findings from the fieldwork and hydrogeologic assessment. The results will be presented in the following order; the refugee's attitude towards the sanitation situation, the present wastewater- and sanitation system and the hydrogeological conditions at site.

## 4.1 LOCAL HOUSEHOLDS ATTITUDES TOWARDS THE SANITATION SITUATION

The purpose with the conversations with the refugees was to find out what the households thought about the present system, how they would respond to a change and to consider the social implication of introducing a new and more sustainable wastewater- and sanitation system. The research findings are presented in the following sections.

### 4.1.1 PEOPLES PRACTICES AND PREFERENCES

A total of 21 households in Yasmine camp were interviewed during the research period, and 18 of them had Arabic style slab toilets. Family latrines inside each dwelling seemed to be an acceptable and preferred solution. The solution provided protection and safety for each family, and the households were responsible to keep their own toilet clean.

The respondents reported no problems with odors, flies or other insects, cleanliness or operation. In addition to this, they told me that they were provided enough facilities, such as cleaning items, soap for handwashing and bin for disposal. The women and girls were asked if they were provided menstrual hygiene materials if needed, and everyone answered yes. The respondents were in general very satisfied with the present water- and sanitation system, cf. Figure 4.1.

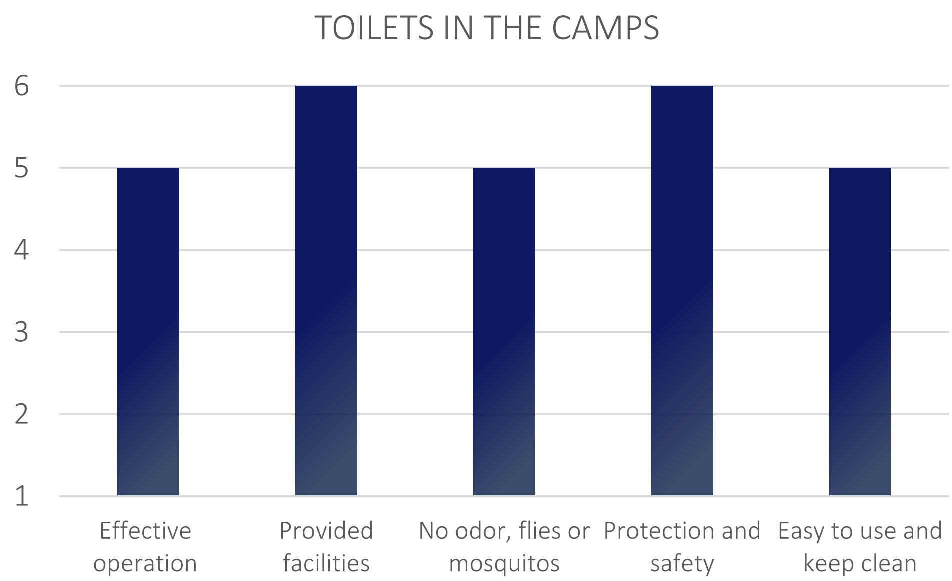



Figure 4.1: The quality of toilets rated on a scale from 1=poor to 6=good (21 respondents)

At the focus group discussion with the women, it was mentioned that the elderly and physically challenged people would probably prefer a toilet where they could sit. This type of toilet was constructed before the hand-over of the project, but there is no public toilet like this in the camps today. These toilets should be available for those who need it, and the families with physically challenged or elderly people should be prioritized and placed where these facilities are provided.

Someone mentioned that they used to have challenges before the rehabilitation, and that flooding, and problems with leakages happened frequently. They said that this was not the case anymore and they were also were happy to not have to pay for the sanitation facilities. They only pay for the electricity in the camps today, and the amount is maximum US $50 a month per family.

### 4.1.2 OBSERVATION OF THE TOILETS AND FACILITIES

After each interview the respondents were kindly asked to show their toilet, and I took some pictures and notes after the observation. According to the Sphere Handbook (Sphere Association, 2018), toilets need to be safe to use and provide privacy, easy to keep clean and use, and avoid to present an environmental hazard that could potentially threaten the surrounding natural environment. In addition to this, the toilets should have locks inside, lighting, no smell, flies or mosquito breeding and the necessary facilities for handwashing, cleaning, anal cleansing and flushing should be provided.

Every household were provided with the necessary facilities, and the toilets looked overall very well-maintained. The toilets did not have ventilation chimneys or windows, but they had lighting inside the toilet, and they did not smell bad.

### 4.1.3 OPENNESS TO SUSTAINABLE SANITATION

The respondents were in general very open-minded and positive to changes. They were all convinced that if a more sustainable solution would benefit them, they thought it should be implemented. Individual users are the ultimate decision-makers in the acceptance or rejection of new solutions. They will determine the success of a project since the value of the investment depends consent of households and the individual users.

Different solutions were explained and discussed with the refugees as visionary components of future on-site systems, such as source-separating systems, production of biogas and nutrient recovery from the human excreta. They discovered values of an improved sustainable sanitation system and thought this could outweigh the potential costs. The discussions with the participants increased the attention to these topics and will hopefully encourage the people to become more engaged, and enable the refugees to develop a sustainable life for themselves

When asked if they could choose between the different solutions, according to their own needs and priorities, 70 per cent wanted a sustainable sanitation solution that could provide them electricity. Their access to electricity is not a matter of course, and they are only promised a minimum of 2 hours per day, thus liked the idea of using human excreta as a resource to receive more energy.

## 4.2 PRESENT WASTEWATER- AND SANITATION SYSTEM

The present wastewater- and sanitation system in the refugee camps was considered through field tests and observation at site. This included inspection of the toilets, estimation of the wastewater generation and assessment of the existing on-site greywater treatment solution. The research findings are presented in the following sections.

### 4.2.1 TOILET SYSTEMS AND EXCRETA DISPOSAL

The families used either Arabic style slab toilets or Western button-flush sitting toilets. The Arabic style slab toilet consisted of a squatting plate, u-bend water seal, bucket for flushing and a water source for anal cleansing next to the toilet. The Western button-flush toilet consisted of a water tank that supplied water for flushing, a water seal and a seat. The latter type of toilet required a larger volume of flushing water, than the technically simpler pour-flush slab toilet. The dimension of the toilet inside the tent, caravan or reinforced cement-block shelters was 1x1x2 m. Flushing water and excreta went down in the toilet, whereas the drain next to the toilet was for washing, shower and laundry water as shown in Figure 4.2.

Figure 4.2: Different types of toilets inside the camps; Arabic style slab toilet and Western button-flush toilet

The blackwater content from each household's toilet was discharged through 4” PVC pipes, to 6” PVC pipes connected to a shared holding tank of 24.5 $m^3$ per every fortieth household. Once the holding tanks were full, desludging trucks collected the content and transported it to either Joub Janine or Zahlé wastewater treatment plants. The transportation and emptying of the septic tanks were costly and the received treatment (secondary biological treatment only) did not allow for recycling, and thus was the solution unsustainable. IOCC payed US $10/$m^3$ for the emptying and transportation of wastewater.

### 4.2.2 WASTEWATER GENERATION

The wastewater generation was estimated based on the filling frequency of the non-portable tanks, and the desludging and emptying frequency of the holding- and septic tanks. The average consumption per person per day is calculated from a total population of 1059 people in Yasmine camp and 1128 people in Awda camp.

Table 4.1: Amount of wastewater and water generated Yasmine- and Awda camp

| | Unit | Yasmine camp | Awda camp |
|---|---|---|---|
| Blackwater | L/pe/day | 10.75 | 12.64 |
| | $m^3$/day | 11.38 | 14.26 |
| Greywater[1] | L/pe/day | 28.94 | 36.60 |
| | $m^3$/day | 30.65 | 41.28 |
| Drinking water | L/pe/day | 5.22 | 4.58 |
| Total water consumption | L/pe/day | 44.27 | 53.82 |

Note: [1][This amount includes water used for toilet flushing]

According to the World Health Organization (WHO), between 50 and 100 liters of water per person per day are needed to ensure that most basic needs are met, and few health concerns arise (UN, 2010). To survive in an emergency, only 15 L/pe/day of water is necessary according to the Sphere handbook and UNHCR guidelines recommends 20 L/pe/day. However, the context in the refugee camps has changed from emergency to stabilization phase, and the amount of water- and wastewater generated in the refugee camps are relatively low.

### 4.2.3 SOIL INFILTRATION OF GREYWATER

Soil infiltration is a simple and robust method for on-site greywater treatment, if the soil conditions are suitable (Jenssen et al., 2006). After pretreatment in the septic tank, the greywater was pumped through the pipe network and to the Northwest end of the camps. There was constructed a soil infiltration trench in this area, where the liquid content could be infiltrated through the coarse layer of gravel and the natural underlying soil. Most of the treatment should occur in the unsaturated zone over the groundwater table, due to aerobic conditions that generally contribute to more rapid die-off of pathogens (Jenssen & Siegrist, 1990).

The infiltration trench measured 16 by 4 meters, which gave a total surface area of 64 $m^2$. The area was covered with a 20-30 cm layer of gravel directly over the natural silty clay soil and pipes. The pipes were 6" perforated in ductile uPVC material and crossed each other as seen on Figure 4.3 below. There were four long pipes along with the infiltration trench, and four shorter ones crossing beneath them, that will collect some of the content and discharge it into the drainage channel.

Figure 4.3 (left): The way the pipes cross each other in the soil infiltration trench in Awda camp, Figure 4.3 (right): Backfilling with a layer of gravel over the natural underlying soil and pipes

Based on the infiltration tests, the maximum infiltration capacity in the trench was assumed to be approximately 6 L/$m^2$/day (section 4.3.2). This means that the soil infiltration trench will only be able to receive about 384 L/day for optimal treatment conditions. According to Table 4.1, around 30 $m^3$/day greywater is generated in each camp, and the way the pipes cross each other will not enable the content to be distributed in time and space. In my opinion, the construction of the infiltration trench was not optimal, the defined area was too small, and the treatment efficiency is most likely low, caused by an overloaded area.

The greywater quality analysis results from the samples taken on 11th and 18th of March are presented in Table 4.2 below. The results are compared to literature data of typical greywater characteristics from other source-separated sanitation systems in the world, and the Lebanese regulations for effluent discharge after treatment.

Table 4.2: Comparison of the laboratory results with typical greywater characteristics from literature data and the Lebanese regulations for effluent discharge

| Parameter | Worldwide (Ghaitidak & Yadav, 2013) | Average Europe (Meinzinger & Oldenburg, 2009) | Average literature (Henze & Comeau, 2008) | Norway, Kajaveien (Todt et al., 2015) | Laboratory result (GW before treatment) | Standards for effluent discharge[1] |
|---|---|---|---|---|---|---|
| $BOD_5$ mg $O_2$/L | 23-942 | 205-449 | 100-400 | 140-160 | 1015 | 25 |
| COD mg $O_2$/L | 55-2000 | 350-783 | 200-700 | 250-300 | 3510 | 125 |
| TSS (mg/L) | 11-2180 | 228 | 40 | 66-89 | - | 60 |
| Nitrogen (mg N $L^{-1}$) | 6.44-75 | 6.7-22 | 8-30 | 16-19 | - | 30 |
| Phosphorous (mg P $L^{-1}$) | 0.012-51.58 | 0.4-8.2 | 2-7 | 1.3-1.6 | - | 10 |
| Total coliforms (CFU/100 mL 37 °C) | [2]200-2.2 x $10^7$ | - | - | - | >2.0 x$10^5$ | 2000 |
| Fecal coliforms (CFU/250 mL 44 °C) | [2]13-1.9 x $10^7$ | - | - | - | >3.0 x $10^4$ | - |
| Escherichia coli (CFU/250 mL 44 °C) | [2]10-3.9 x $10^5$ | - | - | - | 2.0 x $10^3$ | - |

Note: [1][The emission limit values (ELVs) for wastewater discharge from decision 8/1, March 2001], [2][Measured by most probably number (MPN)]

Greywater in low-income countries, compared to high-income countries, is often more concentrated due to low water consumption, and the different parameters are hence commonly higher (Ghaitidak & Yadav, 2013). As Table 4.1 showed, the calculated wastewater generation in the camps was relatively low, and the laboratory results showed that the sample of greywater was highly concentrated. The BOD and COD values were the most critical numbers, and to fulfill the requirements for effluent discharge, the treatment performance in the soil infiltration trench need to achieve approximately 98 per cent removal of BOD and 97 per cent removal of COD. If the waste strength is this high, then technology that can be efficient at reducing the pollution parameters to meet the required limits for effluent discharge or reuse, as described in chapter 5, will be necessary.

## 4.3 HYDROGEOLOGICAL ASSESSMENT

The local conditions were determined through a hydrogeological assessment at site. This included soil sampling and an inspection of the soil, in addition to infiltration tests to determine the hydraulic conductivity and the suitability for infiltration. The research findings are presented in the following sections.

### 4.3.1 SOIL CONDITIONS

The laboratory inspection gave an indication of a fairly well-sorted fine-grained silty clay. Most of the grains were below 2 mm. Out of 100 g, only 0.3 g of the soil sample was above 2 mm in size. After the soil was dried out, it looked like cement and when water was poured into the sample, the soil dissolved into a muddy texture. The tested pH value was 8.12, an indication on content of lime. Hydrochloric acid (HCl) where added to the largest particles, and the following effervescence confirmed a reaction with calcium carbonate ($CaCO_3$), which was present in this soil. The high pH was not surprising considering the sedimentary bas rock in the area that contained lime- and marlstone (section 2.1.1). Fine-grained silty clay soils are usually a good barrier against pollutants reaching the groundwater. However, in the upper part of the soil profile, macropores and aggregation could be observed. Due to the macropores, and the high perched water table, the groundwater was vulnerable to pollution.

Figure 4.4 (left): The soil aggregates (tray) and muddy texture (spoon). Large particles above 2 mm are presented in the sieve (upper left), Figure 4.4 (right): The reaction between HCl and $CaCO_3$ in the soil sample

### 4.3.2 HYDRAULIC CONDUCTIVITY AND SUITABILITY FOR INFILTRATION

The results from the falling head pit infiltration tests are presented in Figure 4.5, based on the measurements in Appendix V. The drop in water level was fast to begin with, and then decreased gradually with an almost constant value. This decreasing trend could be explained by lower pressure head as the water column drops. Silt particles will be washed out and occlude the bottom, and this could also be the reason for the lower infiltration rates in the end.

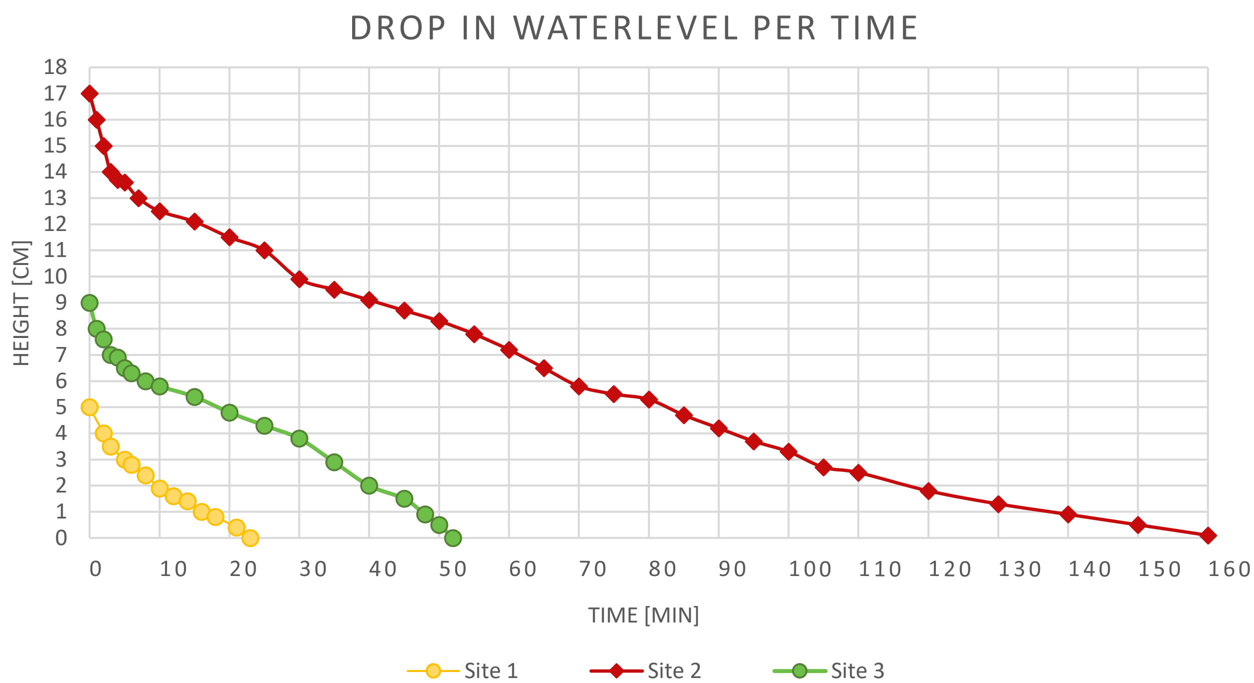



Figure 4.5: Infiltration measurements - Drop in water level per unit time at site 1, 2 and 3

Average infiltration rates for the three different sites are calculated and presented in **Figure 4.6** below. The figure shows that the average infiltration is overall very similar but will decrease with time.

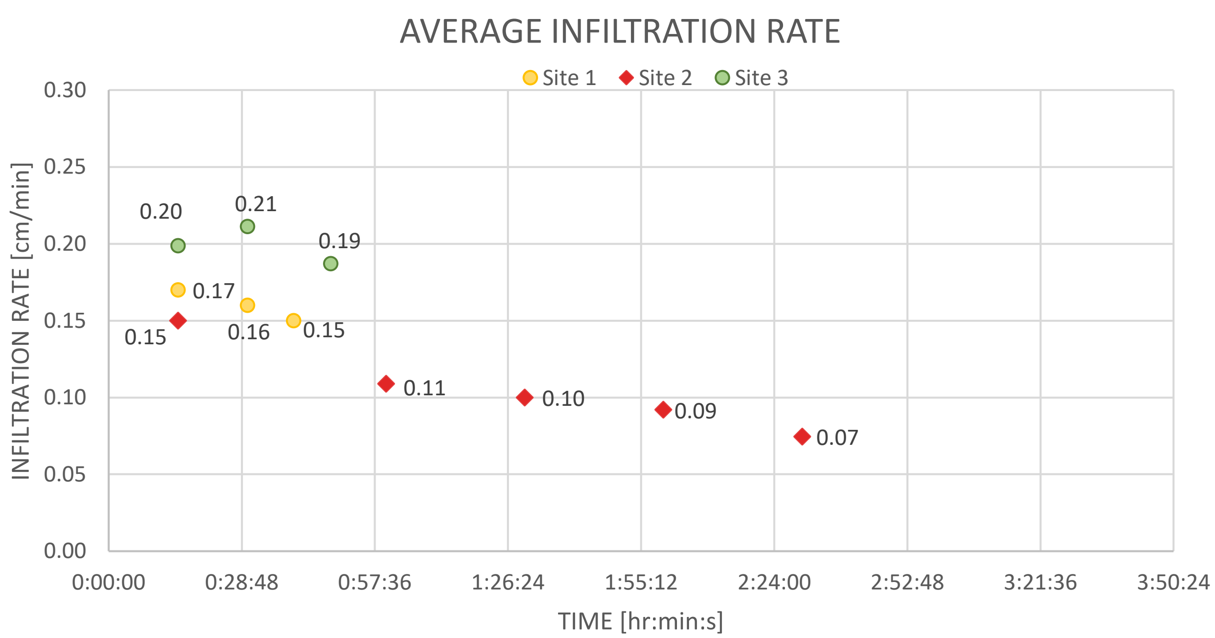



Figure 4.6: Average infiltration rates at site 1, 2 and 3

Assuming vertical infiltration only, the average rates for site 1, 2 and 3 are presented in Table 4.3 below. These values gave an indication of the saturated hydraulic conductivity, $K_{sat}$, but are higher than $K_{sat}$ because the water infilters in three dimensions from an open pit. The water for measurement was reasonably clear, and the infiltration of wastewater will lead to clogging, and hence the long-term infiltration rate for wastewater will be even lower than the following results.

Table 4.3: Vertical infiltration rates for site 1, 2, 3 calculated from the measurements

| Location | Vertical infiltration rates |
|---|---|
| Site 1 | $2.67 \times 10^{-5}$ m/s<br>2.30 m/d |
| Site 2 | $1.889 \times 10^{-5}$ m/s<br>1.632 m/d |
| Site 3 | $3.33 \times 10^{-5}$ m/s<br>2.88 m/d |

Norwegian guidelines (VA-miljøblad., 2018), do not recommend infiltration in soils with $K_{sat}$ below 1 m/day. The values above belong to class 1 in the Norwegian system, and the actual values for $K_{sat}$ will be even lower than these values. For an average saturated hydraulic conductivity of 1-2 m/d, the maximum infiltration capacity will be 6 L/m$^2$/day or 12-18 L/m$^2$/day with biological pretreatment.

In conclusion, the silty clay soil at depth down to 60 cm at site 1, 2 and 3, was aggregated and had a limited suitability for wastewater infiltration. The hydraulic capacity; the ability of the soil to transport water away from the infiltration site, was also limited due to the flat landscape, thus low hydraulic gradients. The soil was fine-grained and was assumed to have a low $K_{sat}$ that could sustain low wastewater loading rates only. The maximum investigated (pit) depth was 60 cm, and there might be coarser deposits with greater permeability and suitability for infiltration beneath the silty clay soil. More infiltration tests and deeper excavations will be necessary to expand the knowledge of the soil conditions with respect to infiltration.

# 5. SUSTAINABLE SANITATION OPTIONS

The present wastewater- and sanitation system in Yasmine and Awda informal settlements is highly dependent on external funding to persist, and it is therefore necessary to find a more long-term and sustainable solution. Sustainable sanitation is an approach with certain principles rather than a specific technology, as there are several different technologies that can be used to make a solution more sustainable (Kalbermatten et al., 1980). This kind of solutions aim to be economically affordable, easy to construct and operate, environmentally sustainable and socially acceptable, and this is important factors when selecting the most appropriate solution (Massoud et al., 2009).

Table 5.1: Factors to consider when selecting the most appropriate solution (After: Massoud et al., 2009)

| Economically affordable | Environmentally sustainable | Socially acceptable |
|---|---|---|
| -Investment cost<br>-Operation and maintenance<br>-Lifespan<br>-Technology efficiency<br>-Population density | -Cyclic system<br>-Environmental protection<br>-Water reuse<br>-Nutrient recycling<br>-Resources conservation | -Institutional framework, policies and strategies<br>-Refugee camp setting<br>-Social and cultural aspects<br>-Involve the local people in the planning and decision-making processes |

## 5.1 IMPROVEMENTS OF THE SYSTEM AND IMPLEMENTATION OF NEW SOLUTIONS

In this chapter, various options will be discussed with a brief explanation, design and construction criteria, required operation and maintenance, strengths, weaknesses, adaptability and potential at site. The following proposed alternatives are selected among many others, to be appropriate solutions in the refugee camps. This choice is based on the local conditions at site and the data gathered during the research period. The separation system of grey- and blackwater in the camps should remain, but some changes and improvements will be necessary to achieve more sustainable management and reuse of more wastewater resources on-site.

### 5.1.1 PRETREATMENT

The tanks in the refugee camps are made with a simple construction, where the blackwater tank work as a holding tank, with one chamber only, without overflow. The greywater septic tank has two compartments, but the treatment efficiency could be improved with an effluent filter vault or anaerobic conditions that will provide attached growth. Modification of a septic tank is possible to improve the system, and some options are presented in the following sections.


Figure 5.1 (left): The BW holding tank and GW septic tank in Yasmine camp (Photo: NCA, 2016), Figure 5.1 (right): Inside the one-chamber BW holding tank (Photo: IOCC, 2014)

#### Septic tank

A septic tank is a watertight chamber made of concrete, plastic, PVC or fiberglass, which wastewater flows through for primary treatment, before any further treatment.

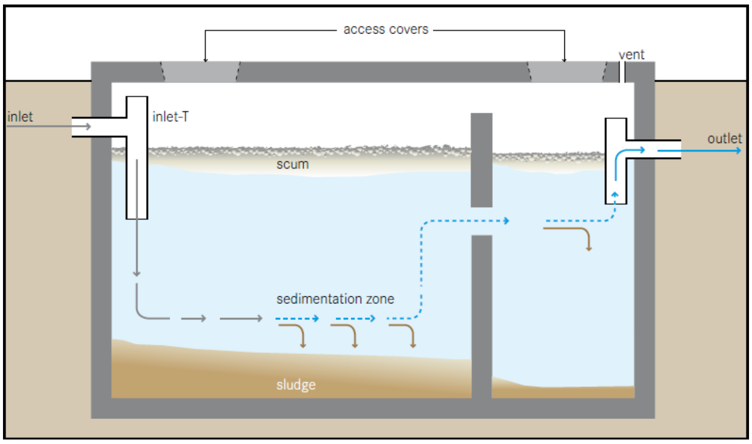



Figure 5.2: Design principle for a septic tank (Tilley et al., 2014)

| | |
|---|---|
| Working principle | *A septic tank should function with settling of solids, flotation of grease, storage of sludge and anaerobic decomposition of accumulated organic matter. Proper functioning septic tanks ensure that the solids settle, and that the sewage network transports the liquid portion only (Hammer & Hammer, 2007).* |
| Design criteria | *The septic tank should consist of at least two compartments, where most of the sedimentation will occur in the first chamber (Metcalf & Eddy Inc. et al., 2014). The first chamber should be half to two-thirds of the total length of the tank. Separation between the chambers will prevent solids and scum to escape with the effluent, and there will be* |

| | |
|---|---|
| | *no short-circuiting through the tanks (Gensch et al., 2018). A T-shaped outlet pipe will reduce the scum and solids that are discharged even more. Accessibility to all chambers is necessary for maintenance, and the tank should be ventilated for controlled release of potentially harmful gases and odorous (Tilley et al., 2014).* |
| Operation and maintenance | *The septic tank should be monitored to control the scum and sludge level, and to assure that the system is functioning well. The tanks should also be checked on a regular basis to ensure that they are watertight. The desludging frequency depends on the size of the tank, number of users and wastewater generation (Gensch et al., 2018).* |
| Treatment efficiency | *The expected treatment efficiency in a properly designed and operated septic tank is around 50-70 % removal of suspended solids, 1-log removal of E.coli and 25-40 % $BOD_5$ removal (Crites & Tchobanoglous, 1998).* |
| Strengths | *The septic tank provides a simple and robust technology, with low operating cost and a long-life span. The area requirement is moderate, and there will be no electrical energy needed (Gensch et al., 2018).* |
| Weaknesses | *The reduction in pathogens, solids and organic material is low, and the effluent require further treatment. Desludging, transport, treatment and disposal need to be taken into consideration (Gensch et al., 2018).* |
| Potential at site | *The already existing tanks need to be checked if they are constructed in an expedient and efficient way, and that they are all functioning well. The BW holding tanks could be upgraded to septic tanks, or to one of the following pretreatment options described in the next sections. Another option is to close the existing holding tanks and let them work as a biogas settler (BS) or biogas septic tank (BST). This will make it possible to produce biogas, especially if organic waste (animal excreta and food waste) are added in the blackwater stream.* |

### Anaerobic baffled reactor

Anaerobic baffled reactor (ABR) work on the same principle as the septic tank but will provide an improved treatment because of the series of baffles they consist of. The wastewater is forced to flow up-stream, and the contact time between the entering wastewater and the active biomass in the accumulated sludge will increase. The pre-settled wastewater will undergo anaerobic degradation, and this will enhance the removal efficiency of solids and organic pollutants (Tilley et al., 2014).

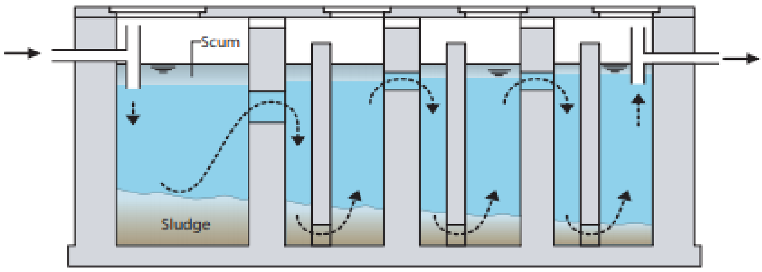



Figure 5.3: Design principle for an anaerobic baffled reactor (Gensch et al., 2018)

| | |
|---|---|
| Working principle | *Vertical baffles in the reactor force wastewater to flow under and over them as it passes from the inlet to the outlet, thus guaranteeing intense contact between wastewater and resident sludge. This solution will increase the sedimentation of settleable solids, flotation of grease and the anaerobic degradation of suspended and dissolved solids (Tilley et al., 2014).* |

| | |
|---|---|
| Design criteria | *The ABR consists of (1) a first chamber that allows sludge to settle on the bottom, and grease and oils to form scum on the surface. This chamber should be equipped with a ventilation pipe for controlled release of potentially harmful gases and odorous created by anaerobic bacteria. (2) Several chambers separated by baffles, where accessibility to all of them is necessary for maintenance. The last chamber should be equipped with an effluent outlet pipe connected to the sewerage system.*<br><br>*The main design criterion is the sizing of the tank and different chambers, that should be proportional to the volumes of wastewater discharged, in order to ensure optimal treatment.*<br><br>*HRT=48-96 h, $V_{max}$= 0.3-1 m/h, 1 sedimentation chamber, at least 3-6 up-flow chambers, typical inflow range from 2 to 200 $m^3$ (Gensch et al., 2018).* |
| Operation and maintenance | *The ABR require expert design and construction, and the start-up period is often long. This is because the slow growing anaerobic biomass first need to be established in the reactor, to reach full treatment capacity. Inoculation with old sludge from the holding tanks could shorten the start-up phase. The scum and sludge level need to be controlled on a regular basis, and the ABR must be watertight (Gensch et al., 2018).* |
| Treatment efficiency | *$BOD_5$ = 70-90 %, TSS ≤80 %, Tot-N ≤20 %, low pathogens and nutrients reduction (BORDA., 2010).* |
| Strengths | *High treatment performance ($BOD_5$, solids and organic matter), long biomass retention time, low sludge yields a long-life span. The ABR will be resistant to shock load and variable inflow and could provide low operating costs. The area requirement is moderate, and there will be no electrical energy needed. The potential to produce biogas will increase (Gensch et al., 2018).* |
| Weaknesses | *The construction and maintenance will become more complex than for septic tanks, and the investment cost will be higher as well. An ABR is not efficient at removing nutrients and pathogens, and the effluent will usually require further treatment (Gensch et al., 2018).* |
| Potential at site | *ABRs have mainly been applied in domestic wastewater and blackwater treatment, and long-term greywater treatment experiences are still a few. An ABR could either be integrated as the second section of the greywater septic tank or be a part of the on-site blackwater treatment solution. The result will be an overall better treatment performance, which causes less pollution in the irrigation channel nearby. The effluent will probably require further treatment, especially for blackwater, and an anaerobic filter could be placed downstream the ABR, to increase the treatment efficiency. If these two technologies are installed consecutively, there will be a higher potential to produce biogas. Sludge drying beds could be used to dewater and treat the produced sludge.* |

### Anaerobic filter

Anaerobic filter (AF) combine mechanical solid removal with digestion of dissolved organics. As wastewater flows through the filter, particles are trapped, and organic matter is degraded by the active biomass that is attached to the surface of the filter material (Tilley et al., 2014).

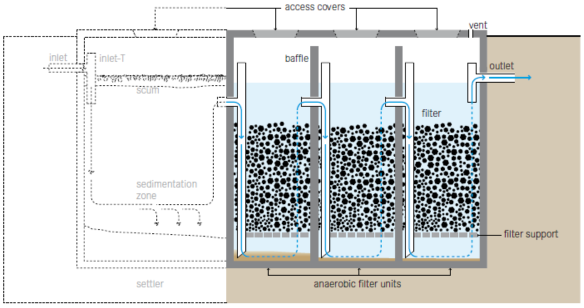



Figure 5.4: Design principle for an anaerobic filter (Gensch et al., 2018)

| | |
|---|---|
| Working principle | *The AF is a fixed-bed biological reactor with one or additional filtration chambers in series. An ideal AF should have a large surface area for bacteria to grow, with pores large enough to prevent clogging. The surface area will ensure increased contact between the organic matter, and the attached biomass that effectively degrades it (Tilley et al., 2014).* |
| Design criteria | *An AF consist of gravel and stones, crushed bricks or rocks, cinder or plastic pipes, depending on the local availability. It is recommended with 2-3 layers of filtering materials (12-55 mm in diameter) within a minimum depth of 0.8-1.2 m. An ideal filter material will provide approximately 90-300 $m^2$ surface area per $m^3$ of occupied reactor volume. The hydraulic retention time in the reactor should be between 12-36 hours (Gensch et al., 2018).* |
| Operation and maintenance | *AF need a start-up period of around 6-9 months. This period could be shorter if the filter is inoculated with anaerobic bacteria, e.g. by adding fresh animal dung or sludge from the tanks. The AF should be monitored to control the level of scum and sludge and to ensure that the system is functioning well. Over time, the growing bacterial mass will become thick, break off and eventually clog the pores of the filter. When the efficiency decreases, the anaerobic filter must be shifted or cleaned. This may be done by backwashing, i.e. run the system in reverse mode or by removing the filter material for cleaning outside the reactor (Gensch et al., 2018).* |
| Treatment efficiency | *$BOD_5$ = 50-90 %, TSS = 50-90 %, Tot-N ≤ 15 %, low pathogens and nutrients reduction (BORDA., 2010).* |
| Strengths | *High treatment performance ($BOD_5$, solids and organic matter), low sludge production, a long-life span. The area requirement is moderate, and there will be no electrical energy needed. The potential to produce biogas will increase (Gensch et al., 2018).* |
| Weaknesses | *This solution will require expert design and construction, the reduction of pathogens and nutrients is low. There will be a risk of clogging (depends on pre- and primary treatment), removing and cleaning of a clogged filter media could be difficult (Gensch et al., 2018).* |
| Potential at site | *An AF is suitable for effluent with a low content of suspended solids and a narrow COD/BOD ratio, and could therefore be installed as post-treatment after a BS/BST or an ABR. If an ABR and an AF are installed consecutively, there will be a higher potential to produce biogas. Sludge drying beds could be used to dewater and treat the produced sludge.* |

### Upflow anaerobic sludge blanket

Upflow anaerobic sludge blanket (UASB) is a tank filled with anerobic granular or flocculant sludge. The solution provide anaerobic degradation of organic matter and subsequent separation to occur in a single reactor (Monvois et al., 2010).

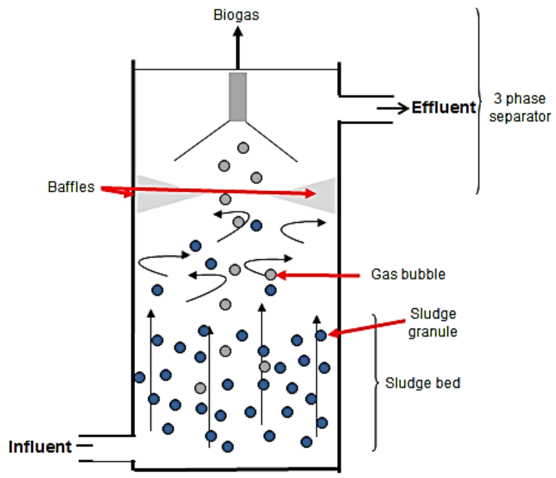



Figure 5.5: Design principle for an upflow anaerobic sludge blanket (Monvois et al., 2010)

| | |
|---|---|
| Working principle | *The wastewater will enter the reactor from the bottom, and flow upwards through a sludge blanket. Bacteria living in the sludge will break down organic matter by anaerobic digestion and transform it into biogas (Larsen et al., 2013). The gas bubbles will move up together with the upward effluent and dispersed light sludge. A 3-phase separator will retain sludge by settling, and the effluent will hence not contain any settable solids. Baffles at the top of the reactor will prevent outflow of the sludge granules and allow the gases to escape (Monvois et al., 2010).* |
| Design criteria | *The reactor should be constructed in concrete or another watertight material. Critical elements for the design are the retention time in the reactor, the wastewater flow and the composition of the sludge.*<br>*HRT=minimum 2 hours (2-20 hours in general). Optimal pH = 6.3-7.85 (to allow the bacteria to grow), and temperature = 35-38 °C. Upflow velocity = 0.7-1 m/h. The sludge blanket is comprised of granules between 0.5-2 mm in diameter that contains microorganisms (SSWM, 2018).* |
| Operation and maintenance | *The UASB need to be constructed, maintained and operated by professionals. The desludging frequency depends on the size of the tank, number of users and wastewater generation, but is in general infrequent. Excess sludge could potentially be removed every 2-3 years (Tilley et al., 2014).* |
| Treatment efficiency | *$BOD_5$ = 55-90 %, COD = 60-80 %, TSS = 60-85 %, low pathogens and nutrients reduction (SSWM, 2018).* |
| Strengths | *High treatment performance ($BOD_5$, COD solids and organic matter), low sludge production and a long-life span. The area requirement is moderate, and the footprint will be small. The operational costs will be low; normally no other costs than for desludging and operation of repair parts, e.g. feeding pumps. The potential to produce biogas will increase (Tilley et al., 2014).* |

| | |
|---|---|
| Weaknesses | *This solution will require expert design and construction and need several months to start up. The investment costs are relatively high, and there will be difficult to maintain proper hydraulic conditions (the hydraulic load must correspond with the upstream velocity and with the organic load). An UASB is not appropriate for cold regions and small communities without a constant water supply and electricity. The effluent and sludge require further treatment to remove pathogens and nutrients (Tilley et al., 2014).* |
| Potential at site | *This solution has the potential to provide higher effluent quality than the already existing septic tank, in a smaller reactor volume. The UASB has also the potential to produce biogas, and this will increase considerably if the wastewater is mixed with organic waste (animal excreta and food waste). The produced biogas could be used as an energy source.* |

### 5.1.2 SOIL INFILTRATION TRENCH

As the laboratory results in Table 4.2 showed, the treatment performance of the soil infiltration trench needs to be very high to fulfill the effluent requirements. Moreover, the infiltration tests conducted at site showed that the silty clay soil was of limited suitability for wastewater infiltration.

To improve the design of the infiltration system, it is possible to construct a mound system. This could be done by adding a 30-50 cm sand layer between the natural soils and the gravel holding the infiltration pipes. Gravel alone is relatively permeable, and an additional layer of sand will enhance the retention capacity of the microorganisms. This will improve the overall treatment performance as the effluent moves downward through the gravel- and sand layer and into the underlying natural soil. However, it must be documented that the underlying soil have hydraulic capacity to absorb, treat and transport the infiltrated water. This requires, as mentioned above, more comprehensive site investigations.

Figure 5.6: Construction of a mound system for a small cabin in Norway (Photos: Petter D. Jenssen)

The distribution pipes should be slightly sloped for gravity pipes, and horizontal for pressure distribution systems, and distribute the content in time and space through the soil. Instead that the pipes cross each other, there should be one trench for each pipe as illustrated in Figure 5.7. This will provide an air flow between the trenches, and the anaerobic clogging zone will be minimized. The water level in the trench should be monitored frequently through vertical control pipes to find out whether the distribution and infiltration functions properly. The main design criterions of such systems are the volumes of water discharged, the infiltration capacity of the soil and the available surface area.

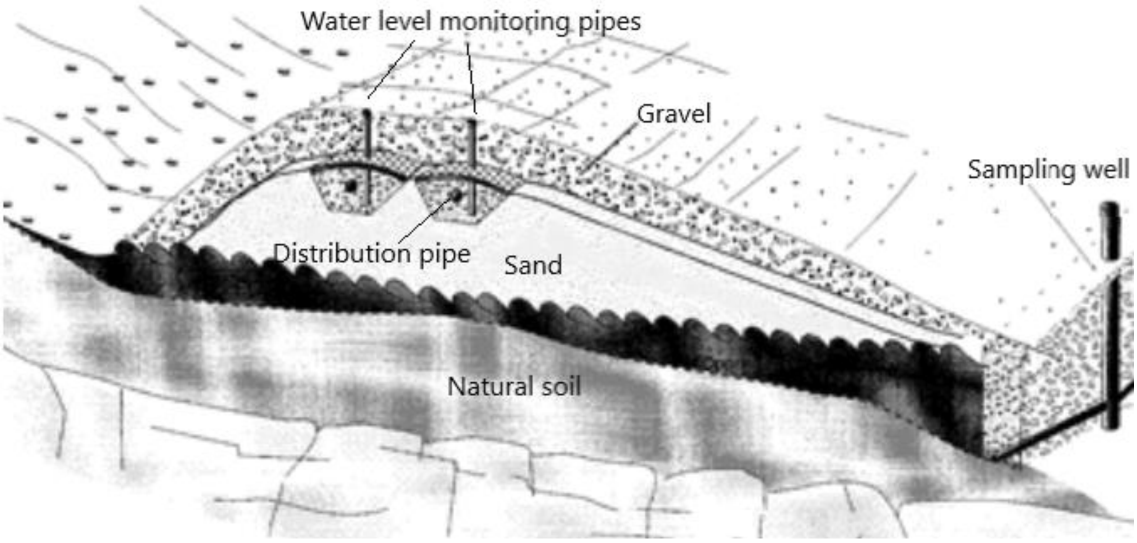



Figure 5.7: Design of an infiltration trench (Jenssen & Heistad, 2000)

### 5.1.3 TOILETS

Toilets in the camp are either Arabic style slab toilets or Western button-flush sitting toilets, and the refugees are in general very satisfied with these solutions. Different solutions could without difficulty be integrated in the existing system for easier handling of the excreta, to reduce the total wastewater volume and potentially produce biogas from the human faeces. This would provide a more sustainable solution with benefits for the refugees as they are given valuable resources in return.

Figure 5.8 summarizes some different options for excreta- and greywater management, and what use and benefits they could provide. Some of the solutions divert faeces, urine and greywater into three fractions, others combine them.

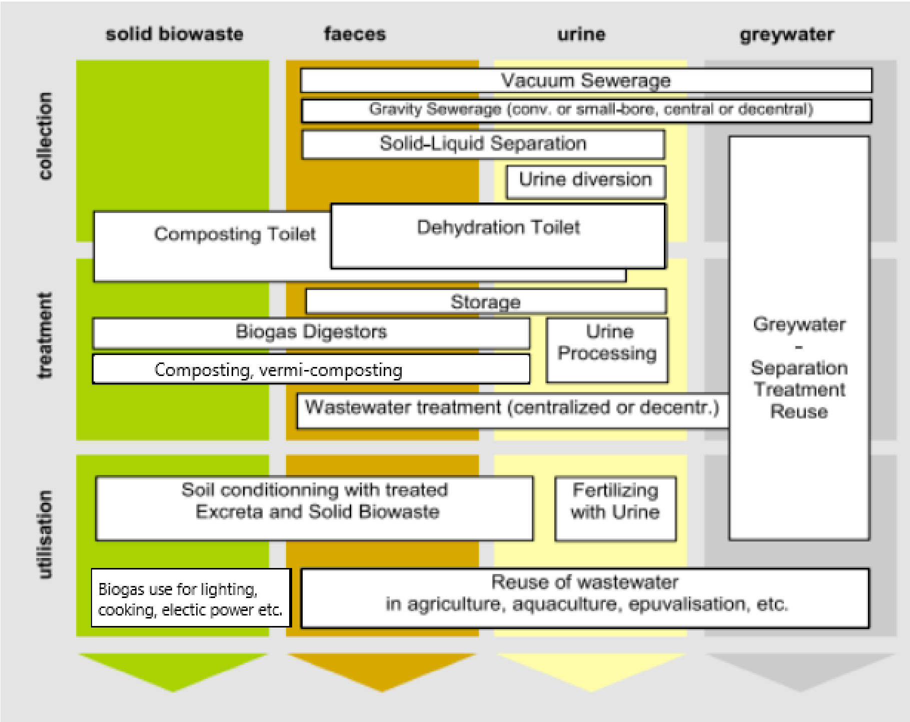



Figure 5.8: Overview of different technologies used management of excreta and greywater (WHO, 2006)

One option in the refugee camps is to connect the toilets to an insulated tank filled with worms and carbon-rich material and make a **vermicomposting toilet.** The composting worms will break down the organic material and convert it into a dry humus-like material and respiration products.

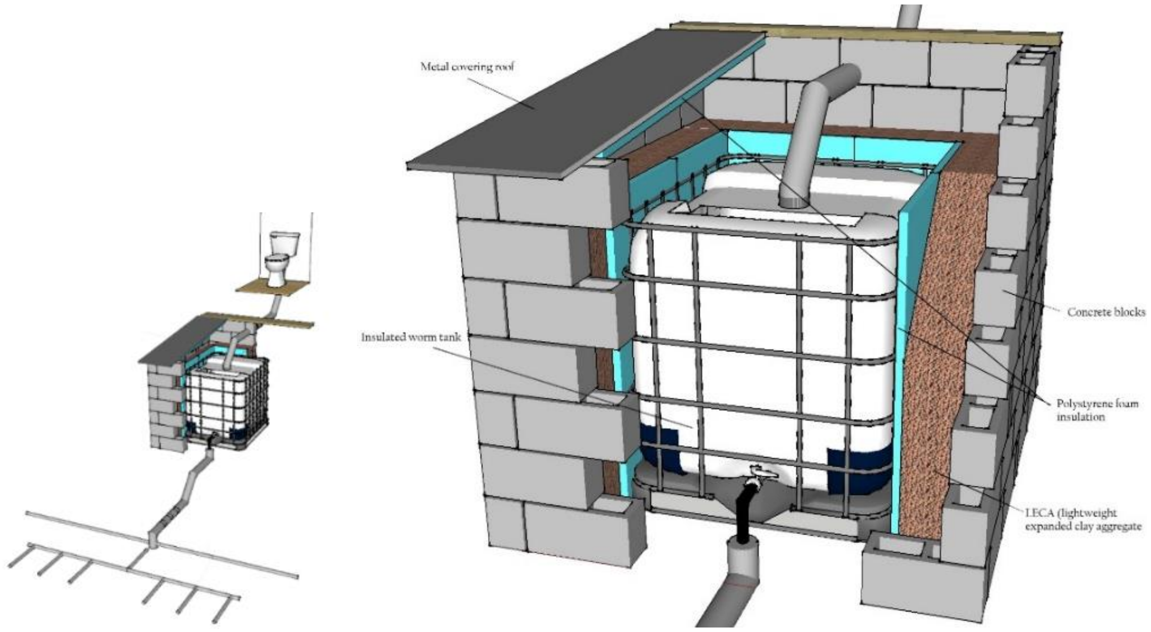



Figure 5.9: Design of a vermicomposting toilet and the construction of the insulated worm tank (Howard & Rocha, 2018)

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| Working principle | *Composting toilets rely mainly on aerobic degradation of organic matter and they have a collection chamber beneath them, where all the excreta are confined. The chamber in this type of toilet is filled with composting worms and carbon-rich material. The solids from the wastewater will remain on the surface to be processed by the worms. The liquids will drain through a vermifilter in the bottom of the tank, and then exit the tank (McBride et al., 2017).* |
| Design criteria | *The collection tank should be insulated, e.g. an IBC tote or pallet tank. There should be a layer of polystyrene foam insulation outside the tank to keep the temperature range optimal for the composting worms (20-25 °C), followed by LECA, concrete blocks and a metal covering roof, cf.* Figure 5.9*. The outlet of the tank should be covered with plastic or nylon mesh to prevent organic material from blocking the outflow pipe network (Howard & Rocha, 2018).*<br><br>*Each household would probably need 0.5-1 kg composting worms to begin with the vermicomposting process, and four species have been successfully used to date namely; Eisenia fetida/Eisenia Andrei (the Tiger worm), Eudrilus eugeniae (the African nightcrawler) and Perionyx excavatus (the Indian blue). The presence of a soil layer will most likely help to increase the earthworm biomass growth.*<br><br>*The C:N ratio should be about 30:1, since vermicomposting processes requires a large amount of carbon. Mixing slow-release carbon-rich material such as wood or bark chips, corrugated cardboard with more bioavailable carbon stores like compost, dry leaves, sawdust and straw, will ensure a good balance that could provide the ecosystem with enough carbon reserves for several months (Yadav et al., 2010).* |
| Operation and maintenance | *The operation and maintenance should include regular cleaning of the toilets, emptying and filling of the tank and minor repairs. It is also important to ensure that the drainage layer is adequate to prevent saturated and anaerobic conditions and allow the water to soak away without ever flooding the worms.* |

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| Strengths | *The process is rapid, cost effective, easily controllable and could accomplish complete elimination of total coliforms and an efficient recycling of organics and nutrients (Yadav et al., 2010). The solution will reduce the solid wastewater volume and give the population a valuable resource in the composting product. The emptying frequency is low (>5 years for a 1 $m^3$ tank).* |
| Weaknesses | *This solution will require training and acceptance to be used correctly. To secure a worm supply could be an issue, and to provide worms to all the refugees could be costly (US $50 per kg).* |
| Potential at site | *This is a simple, easy to construct solution, and the design is adaptable to the already existing system. The composting tanks could either be installed beneath each household's toilet (1 $m^3$ size), or as one large tank before every BW holding tank. The refugees will be given a valuable resource in the composting product, and they could either sell this to farmers in the area or start to cultivate their own crops. A 1-year study has showed that it was possible to convert about 1.5 kg of human faeces into 200-300 g of vermicompost (Yadav et al., 2010). The product could be used as soil conditioning after storage, and the vermifiltered water leaving the tank could go into the pipe network and be sent to further treatment for purification.* |

Another option could be to install an **Urine diversion toilet** (separate the urine and faeces), and allow the faeces to dehydrate, and the urine to recover for beneficial use.


Figure 5.10 (left): Urine diversion squatting pan toilet with a separate anal cleansing bowl (Photo: Johannes Heeb), Figure 5.10 (right): Urine-diverting flush toilet (Photo: Richard Brunt)

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| Working principle | *This type of toilet consists of different pans; one anal cleaning bowl, one pan for faeces and one separate pan for urine. Urine is sterile and concentrated with nutrients that can be applied as fertilizer in the agriculture, or as an additive to enrich compost after being stored. WHO guidelines recommend a storage time of ≥ 6 months (4 °C storage temperature) for food crops that are to be processed, and of ≥ 6 months (20 °C storage temperature) for all crops in general. The nutrients in urine are in a readily form available for the plants, and it contains among others nitrogen (N), phosphorous (P), potassium (K), in addition to boron (B), zinc (Zn) and iron (Fe) (WHO, 2006).*<br>*Dry excreta and faecal sludge could also be reused, after > 1 year of storage time and an optimal temperature range of 20-35 °C. This will provide a total inactivation of viruses and protozoa, and the bacterial pathogens will be eliminated (WHO, 2006).* |
| Design criteria | *This system will require dual plumbing, and the pipes for urine and faeces must be separated. It will be necessary to install an additional bowl to collect the urine* |

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| | *separately. To prevent odors, the piping system should be very sparingly ventilated and the retention tanks for urine and faeces should be covered and closed. On the other hand, it is important to provide enough inflow of air so that the tank does not implode (Gensch et al., 2018).* |
| Operation and maintenance | *As with any other toilet, proper cleaning and maintenance is important. The calcium- and magnesium-based minerals and salts in urine could precipitate and build-up in the fittings and pipes. To wash the bowl with a mild acid (e.g. vinegar), and hot water can prevent the build-up of deposits and scaling. The containers for urine need to be emptied on a regular basis after storage (Gensch et al., 2018).* |
| Strengths | *This system will make a cyclic, sustainable solution for the camps, and could easily be integrated in the present solution. Separation of faeces and urine will make it easier to reduce the total wastewater volume and to handle the excreta properly on-site. The potential to produce biogas will increase considerably without the high concentration of ammonia and nutrients (phosphorous and nitrogen) in the urine.* |
| Weaknesses | *This system will require training and acceptance to be used correctly and will also be prone to misuse and clogging. Some faecal contamination of the urine could happen, which may pose a potential risk if the urine shall be used as fertilizer.* |
| Potential at site | *Urine diversion toilets could be integrated in the existing system by installation of an additional bowl to collect the urine separately. A collection container for urine could be installed beneath each toilet for storage, while the faeces and flushing water flows further into the holding tanks. This system will make the handling of excreta easier, the total wastewater volume in the tanks will decrease and the urine could be used as liquid fertilizer in the fields. The potential to produce biogas will increase considerably without the high concentration of ammonia and nutrients (phosphorous and nitrogen) in the urine.* |

### 5.1.4 MOBILE SMALL WASTEWATER TREATMENT SYSTEMS

New technology and solutions could also be implemented in Yasmine and Awda informal settlements, and different alternatives have been considered as suitable in the refugee camps. On the market today, there are several suppliers that have developed processes to treat wastewater streams on-site, and among others Orenco® Systems and Biorock® Wastewater Treatment have been contacted and given their personal advice.

**AX-Mobile sewage treatment plant**

Orenco® Systems offer an AdvanTex Treatment System which is a mobile containerized wastewater treatment plant that could treat wastewater in a low-impact, energy-efficient-way.


Figure 5.11: AX-Mobile configuration (*Orenco® Systems., 2017)*

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| Working principle | *All stages of a treatment process can occur on the inside of the AX-Mobile configuration, and the system will include a lift station, primary settling tank or screen, secondary treatment process, disinfection and controls, cf. Appendix VI.*<br>*The primary treatment stage is designed to collect wastewater; separate settleable and floatable solids (sludge and scum); accumulate, consolidate and store solids; digest organic matter; and discharge primary-treated effluent. The primary treatment stage could be done in the existing holding tanks, if they are improved and upgraded to include separation of solids. The next stage is a pre-anoxic treatment step in a separate chamber. The purpose with this is to balance and lower the concentrations (especially nitrogen) of the recirculated recirc-blend (or filtrate) from the secondary treatment step.*<br>*The secondary treatment stage is the AdvanTex Treatment System that is a multiple-pass, packed-bed, fixed-film media filter system. The wastewater will be filtered, cleaned and nitrified by naturally occurring microorganisms as it percolates through the media. After treatment, a portion of filtrate is recirculated to the anoxic zone, whereas the other portion flows to the next treatment step. This could be a post-anoxic treatment stage to provide additional denitrification.*<br>*The last step is disinfection, to remove microbial contamination and to fulfill the effluent standard requirements before discharge. This could be achieved by ultraviolet rays (UV), chlorine or ozonation (Orenco®Systems., 2017).* |
| Design criteria | *According to Table 4.1, the total blackwater flow is low enough to develop a treatment package in a 40" container in each camp. This module will be scaled to a standard container size according to ISO-standards and could therefore be easily transported.* |
| Operation and maintenance | *The system needs to be constructed, maintained and operated by professionals. There will be a quick installation and start-up, followed by low operation and maintenance costs, because the system could be fully automated.* |
| Treatment efficiency | *With appropriate treatment, primary-treated effluent typically ranges from:*<br>*-$BOD_5$ 300-500 mg/L*<br>*-TSS 80-250 mg/L*<br>*-TKN 90-200 mg/L* |

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| | *When loaded at or below the applicable loading rates, standard AdvanTex Treatment Systems typically achieves <10 mg/L $BOD_5$/$cBOD_5$ and TSS, >60 % reduction of the total nitrogen (TN) and 90-99 % removal of ammonia ($NH_3$-N) (Orenco®Systems., 2017).* |
| Strengths | *This solution is an energy-efficient package wastewater treatment system (1-2 kWh per 4000 treated L), that could be monitored and controlled by remote telemetry. This system is not dependent on the soil conditions and could be installed in areas with high water table. The technology has a long-life span and the design allows for expansion. The system is reliable and could provide a high-quality effluent after treatment (Orenco®Systems., 2017).* |
| Weaknesses | *The solution require large space as the system is not suitable to be built underground. The capital cost is high, and the maintenance expertise and time will increase.* |
| Potential at site | *The AX-Mobile configuration will be able to treat a total wastewater flow of 18.9 $m^3$/day, and this solution could be implemented in the refugee camps to fulfill secondary and/ tertiary treatment of the on-site blackwater stream. This will solve the desludging problem and reduce the transportation and emptying cost. The system is reliable and could provide a high-quality effluent after treatment.*<br><br>*If the entire system is to be purchased from Orenco® Systems and delivered to the site, it would cost roughly US $200.000, including installation and commissioning visits. Local sourcing of various components, specifically the tank components, will make it possible to reduce the capital cost.* |

### The Biorock® sewage treatment plant

The Biorock® units are mobile small wastewater treatment plants, that relies on biological purification processes to treat the wastewater. The system use materials with large surface area, to provide colonization of bacteria, and to improve the wastewater treatment.

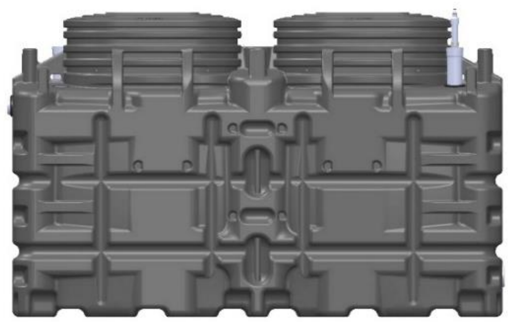

Figure 5.12: ECOROCK-5000 treatment unit (Biorock., 2016)

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| Working principle | *The system functions with two-stages; (1) a primary tank and (2) the ECOROCK-Bioreactor. The raw sewage will first enter the primary tank to provide separation and initial breakdown of organic solids (Primary treatment). Afterwards, the sewage will pass through an effluent filter before discharging into the ECOROCK-Bioreactor unit which incorporates the aerobic digestion process (Secondary treatment) and filtration process (Tertiary treatment), cf. Appendix VII. The units are constructed with layers of BIOROCK® Media, and one layer of plastic rings in the middle. The media has a huge surface area and will work as a carrier material for the bacteria (Biorock., 2016).* |
| Design criteria | *The BIOROCK® units comes in different sizes and could be installed in parallel to fulfill a larger capacity (BIOROCK® 5000-Multirock systems). Each HDPE unit tank will be dimensioned for 30 P.E. capacity, 5000 L volume, 3.500 mm length, 1.150 mm width, 2.175 mm height and a total weight of 679 kg.* |
| Operation and maintenance | *The operation and maintenance costs are minimal, but the compartments need to be changed after a while. The separate primary tank will ensure a long desludging interval of 3-4 years. The BIOROCK® media contains microscopic pollution degrading bacteria, preventing it from clogging, and this material has a 10-years warranty.* |

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| | *Once a year it will be necessary to check the sludge level in the primary tank, and the tank should be emptied if the level is > 50 % full. The effluent filter should also be changed from time to time, the complete system must be watertight and the ventilation must functioning well (Biorock., 2016).* |
| Treatment efficiency | *One ECOROCK-5000 unit was installed in Aarsal, Lebanon (combined grey- and blackwater) in 2018, and here are some results:*<br><br>*<u>Primary tank:</u>*<br><br>*-Oil and grease 118 mg/L*<br><br>*-TSS ≥ 150 mg/L*<br><br>*-$BOD_5$ = 309 mg $O_2$/L*<br><br>*-COD ≥ 15.000 mg/L*<br><br>*<u>After treatment:</u>*<br>*-Oil and grease 85 mg/L (25 % reduction)*<br><br>*-TSS = 89 mg/L (60 % reduction)*<br><br>*-$BOD_5$ = 24 mg $O_2$/L (92 % reduction)*<br><br>*-COD = 177 mg/L (98.8 % reduction)* |
| Strengths | *This solution is implemented in other refugee camps in Lebanon and is a reliable system with high treatment performance. This system is not dependent on the soil conditions and could be installed in areas with high water table. The operation and maintenance costs are minimal. The system has no mechanical components and will not require electrical energy.* |
| Weaknesses | *The BIOROCK® units will require expert design, construction and service. The investment cost will be relatively high, and this solution will require large space.* |
| Potential at site | *The total blackwater stream could be treated on-site with 3 x ECOROCK-5000 units in each camp. If 3 units are installed, the maximum organic load could be 6.75 $BOD_5$/day with a maximum hydraulic load of 13.500 L/day (Biorock., 2016). This could solve the desludging problem and reduce the transportation and emptying cost. The Biorock® treatment system has proved to have a high treatment performance, that could allow the effluent to be discharged directly into the natural environment.*<br><br>*For every ECOROCK-5000 unit installed, it will be necessary with one 10.000 L primary tank. Installation and delivery of one complete unit by Biorock® Wastewater Treatment will cost US $8.300 in total (US $1.300 for the primary tank and Us $7.000 for the ECOROCK-5000 unit). The sum will be approximately US $24.900 for each camp (3 x $8.300). The civil works and VAT are excluded in this price.* |

## 5.2 FUTUTRE TREATMENT OPTIONS

To achieve more sustainable management and reuse of wastewater resources on-site, all the wastewater should be handled in a complex system. The separation system of grey- and blackwater in the camps should remain, but some improvements and implementation of new technologies will be necessary. Figure 5.13 presents an overview of the possible future treatment options in the studied refugee camps, based on the suggested solutions in the previous chapter.

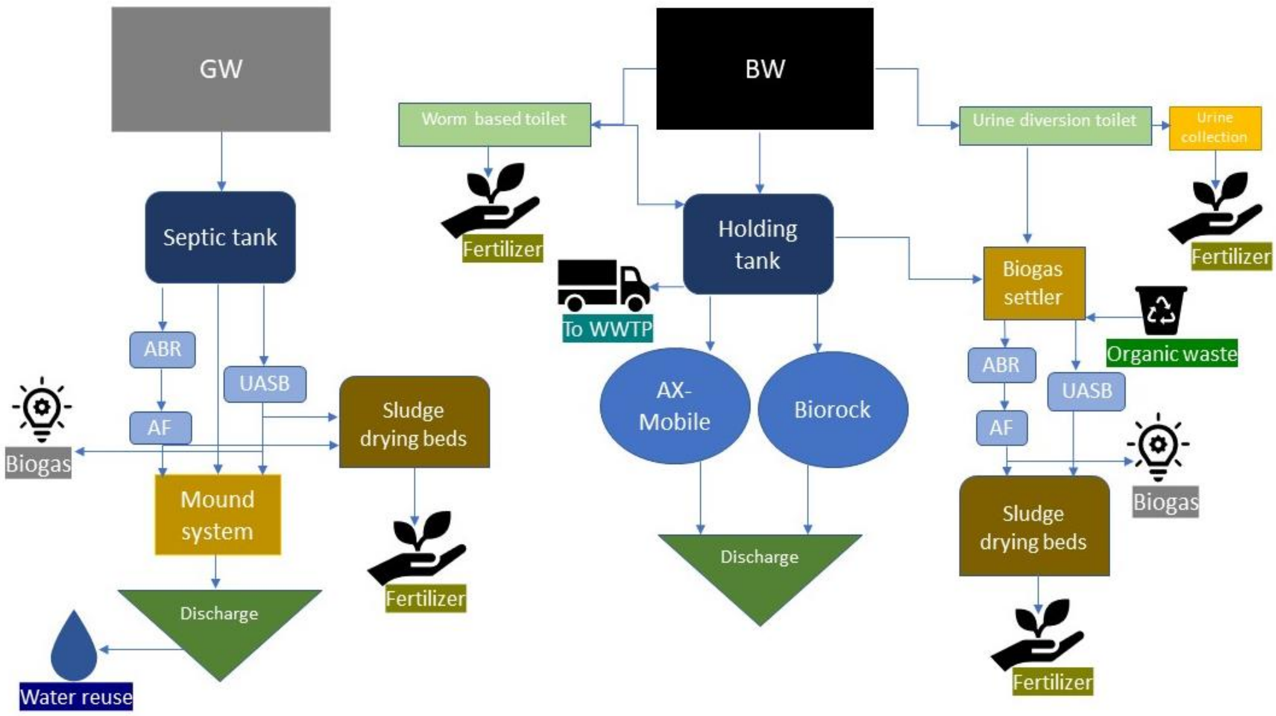


Figure 5.13: Overview of the future treatment options in Yasmine and Awda informal settlements

The pretreatment of greywater should be upgraded as described in section 5.1.1, followed by a mound system as described in section 5.1.2. This will enhance the overall treatment performance, and the treated greywater could be discharged into the irrigation channel without causing more pollution. The sludge from the ABR and AF, or optionally UASB, could be dewatered in sludge drying beds. The remaining solids could be used as soil amendment or solid organic fertilizer in the fields. The refugees could either sell this product to farmers in the area or start to cultivate their own crops. The highly concentrated greywater in the camps also has the potential to produce biogas, and provide energy for cooking, heating and lighting. To save water, the treated greywater should ideally be reused for flushing, gardening purposes or laundry washing. With advanced treatment, conversion of greywater to portable water is possible, and this will provide water self-sufficiency to the refugees. This is something that could be considered in the long run but should not be prioritized for now.

The toilets in the camp should be improved as described in section 5.1.3. Implementation of a vermicomposting toilet could be enough as a temporary solution for the desludging problem and to reduce the emptying and transportation costs. Another option is to install an additional bowl and collection container beneath each toilet to store and collect the urine separately and make a urine diversion toilet. This solution will make the handling of excreta easier and the total wastewater volume in the tanks will decrease. The urine could be used as liquid fertilizer in the fields, while the faeces and flushing water flows further into an insulated and closed holding tank or biogas settler. The potential to produce biogas will increase considerably without the high concentration of ammonia and nutrients (phosphorous and nitrogen) in the urine. The biogas potential will further increase if organic waste (food waste and animal excreta) are mixed into the remaining solid content of blackwater. The blackwater could be treated with similar methods as the ones suggested for the greywater.

If the assumptions to produce biogas with organic waste is too low, and the solution suggested above requires larger area, mobile small wastewater treatment systems could be installed in the camps, cf. section 5.1.4. These solutions are suitable in temporary refugee camps and could be easily transported anywhere. The systems are reliable and could provide a high-quality effluent after treatment. However, the capital cost is high, and these units require expert design, construction and service.

### 5.2.1 EXAMPLE OF A SUSTAINABLE SANITATION SOLUTION

One example of a sustainable sanitation solution is the project in Badlapur Adarsh College, in Maharashtra, India, operating since September 2008. This is a decentralized wastewater management project, where 2600 students are using the system daily, and about 800 people attends special events and visits occasionally (Zimmermann et al., 2009). Figure 5.14 illustrate the wastewater treatment system, and the different technologies applied for this solution.

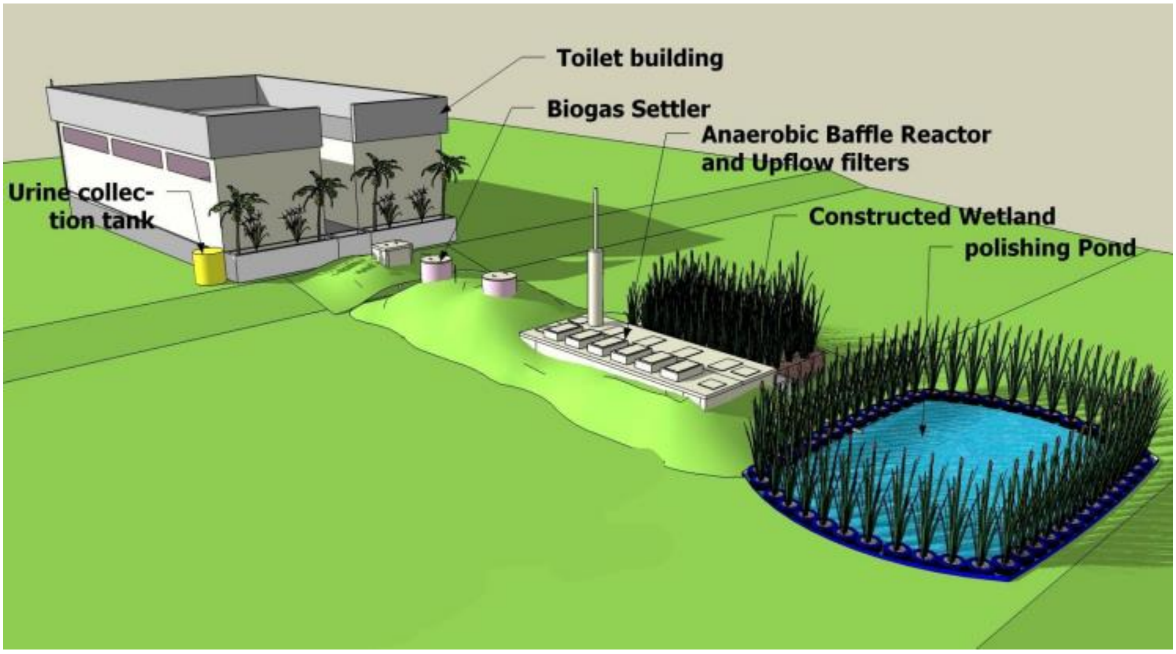


Figure 5.14: 3D-sketch of the system in Badlapur Adarsh College (Zimmermann et al., 2009)

The first step is a single-storied toilet building with independent enclosures for ladies and gents. The toilets have a low water consumption and are mainly pour-flush pans, in addition to some waterless urinals where the urine is collected, and the product is utilized as nitrogen-rich fertilizer. The rest of the blackwater, along with the greywater will be discharged into a biogas settler. The solids will retain in the bottom sludge and could be used, after anaerobic decomposition, to produce biogas and provide energy for cooking, heating or lighting. The effluent will furthermore be drained by gravity to an anaerobic baffle reactor followed by an upflow anaerobic filter. Sludge drying beds will dewater the sludge from the BS, ABR and AF. The product will be faecal sludge that could be used as soil amendment in the garden within the school premises. The last step is natural-based treatment with a horizontal flow constructed wetland, and a polishing pond in the end before final discharge (Zimmermann et al., 2009).

This treatment system is able to handle up to 12 kg BOD each day, and more than 95 per cent of the produced biogas get captured for reuse (Kropac, 2008). Figure 5.15 represent the flowchart for this system, with the expected reduction of BOD.

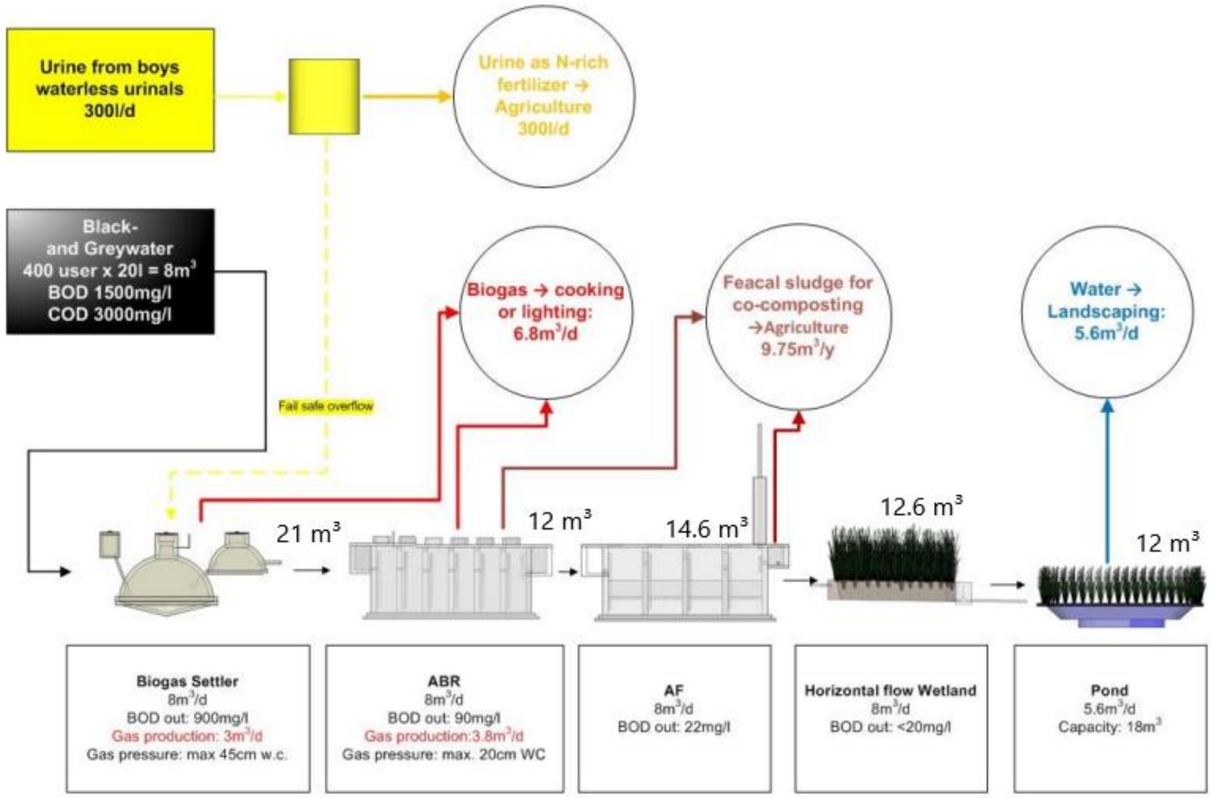


Figure 5.15: Flowchart of the wastewater treatment system in Badlapur Adarsh College (Kropac, 2008)

# 6. CONCLUSION AND FURTHER RESEARCH NEEDS

This study concludes that there is a need for further improvement and change of the present methods for treatment and handling of wastewater within Yasmine and Awda informal settlements. Different possible solutions have been discussed observing the local conditions at site, and several alternatives are pointed out. All the wastewater should be handled in a complex system, to achieve more sustainable management and reuse of more wastewater resources on-site. The separation system of grey- and blackwater in the camps should remain, but some improvements and implementation of new technologies will be necessary.

The present wastewater- and sanitation system is highly dependent on external funding to persist, and the on-site treatment of greywater is not optimal. The soil type in the area is fine-grained silty clay soil which has limited hydraulic capacity. The different wastewater streams generated in the camps were low, thus the greywater sample analyzed in the laboratory was highly concentrated. The on-site greywater treatment system was not optimal, and the design of the infiltration system should be changed. This could be done by adding a sand layer between the natural underlying soil and the gravel holding the infiltration pipes, and construct a mound system.

The final solution for both grey- and blackwater should be based on the systematic implementation of reuse and recycling of nutrients and water as a hygienically safe, closed loop and holistic alternative to conventional systems, like the decentralized wastewater management project in Badllapur Adarsh College (Maharashatra, India). There are several options, as presented in the chapter above, and there is a need for a more thorough fieldwork study, to determine whether implementation of these solutions is possible or not in practice. More and deeper infiltration tests, calculations and sizing of the treatment solutions, in addition to site investigations will be necessary to expand the knowledge of the soil conditions and the suitability at site. The potential to produce biogas from the concentrated greywater, or the blackwater mixed with any available organic waste (food waste and animal excreta) need to be further investigated.

Even though complex or advanced technologies are available, they are not always suited to be used in a refugee camp setting. Several aspects must be investigated for instance; economy, hydrogeological conditions, the culture of the people and host country restrictions. This thesis recommends further interaction with the refugees to cultivate ideas and determine their ability to move forward and have a self-supportive system. Acceptance from the local people is a key factor for a successful project, and they are the ultimate decision-makers.

The refugees were in general very open-minded and positive to changes. They were all convinced that if a more sustainable solution would benefit them, it should be implemented. The result of increased attention to this topic will hopefully encourage someone to solve this problem and motivate the refugees to be more engaged. The way forward will be to get acceptance from the refugees and make a total cost estimate of the project. This must be done before external funding to support the project is applied for.

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## LIST OF FIGURES

## LIST OF TABLES



*Unless otherwise noted, all pictures taken and sketches, tables and graphs are created by the author.*

# APPENDIXES

## APPENDIX I: LIST OF MEETINGS WITH URDA, NGOS AND OTHER WASH-EXPERTS

| Organization | Name | Position | Date | Time |
|---|---|---|---|---|
| Norwegian Church Aid (NCA) | Ioannis Georgiadis<br>Manfred Arlt | Advisor Water, Sanitation and Hygiene (WASH) | January 14, 2019 | 14:00-16:30 a.m |
| Norwegian Church Aid (NCA) and International Orthodox Christian Charities (IOCC) | Ioannis Georgiadis<br>Ziad Abdayem<br>Fadi Haddad<br>Nathalie Riachy | Advisor Water, Sanitation and Hygiene (WASH),<br>Engineer | January 28, 2019 | 09:00-11:00 p.m |
| United Nations Children's Fund (UNICEF) | Maria Saidy | WASH officer | January 29, 2019 | 14:00-15:00 p.m |
| Union of Relief and Development Associations (URDA) | Mohamad Ajram | Project manager | February 4, 2019 | 12:30-13:30 p.m |
| International Orthodox Christian Charities (IOCC) | Rita Saad | Promoter Water, Sanitation and Hygiene (WASH) | February 7, 2019 | 09:00-12:99 p.m |
| Difaf s.a.l | Hussam Hawwa | Founder/Director | February 11, 2019 | 14:00-16:00 p.m |
| CubeX | Marc Aoun | Founder/Project manager | February 20, 2019 | 08:30-11:30 a.m |
| Litani River Authorities | Hanna Hayala | Engineer | February 22, 2019 | 10:00-11:30 a.m |
| Biorock® Wastewater Treatment | Sami Choueiri | General manager | March 28, 2019 | 10:00-11:30 a.m |
| Orenco® Systems | Tristian Bounds | Professional engineer | April 11, 2019 | 08:00-12:00 a.m |
| The Lebanese Organization of Studies and Training | Mohammed Amhaz | Manager Water, Sanitation and Hygiene (WASH) | May 05, 2019 | 12:00-13:00 a.m |

## APPENDIX II: DEMOGRAPHIC INFORMATION OF INTERVIEW RESPONDENTS IN YASMINE IS

| Interview No. | Gender | Age | Occupation | Education level | No. of HH members |
|---|---|---|---|---|---|
| 1 | F | 37 | Housekeeper | Grade 6 | 2 |
| 2 | F | 33 | Housekeeper | No formal schooling | 6 |
| 3 | F | 40 | Housekeeper | Grade 6 | 4 |
| 4 | F | 59 | Housekeeper | No formal schooling | 4 |
| 5 | M | 32 | Volunteer for URDA | Doctor | 2 |
| 6 | F | 23 | Housekeeper | Grade 6 | 5 |
| 7 | F | 30 | Housekeeper | Grade 6 | 4 |
| 8 | F | 26 | Volunteer for IOCC | Grade 7 | 4 |
| 9 | F | 19 | Housekeeper | Grade 6 | 4 |
| 10 | F | 31 | Housekeeper | Banking | 6 |
| 11 | M | 43 | Volunteer URDA | Grade 5 | 7 |
| 12 | M | 29 | Personal worker | Grade 9 | 5 |
| 13 | M | 32 | Carpenter | Grade 9 | 7 |
| 14 | M | 33 | Volunteer URDA | Grade 6 | 6 |
| 15 | M | 31 | Jobless | No formal schooling | 8 |
| 16 | M | 70 | Jobless | No formal schooling | 2 |
| 17 | M | 23 | Jobless | No formal schooling | 3 |
| 18 | M | 34 | Worker outside camp - construction | Grade 6 | 2 |
| 19 | M | 24 | Volunteer URDA (ITS cleaning) | Grade 7 | 3 |
| 20 | M | 40 | Worker outside the camp | Grade 1 | 7 |
| 21 | F | 14 | Farmer | Grade 5 | 9 |

# APPENDIX III: QUESTIONNAIRE

Household Survey at Yasmine informal settlement: Sanitation

Date: Start Time:

Household ID:

Household members:

## INTRODUCTION

Good morning/afternoon/evening. My name is Elisa Winger Eggen and I'm a master's student at Norwegian University of Life Sciences. I want to carry out a research that only will be used for academic purposes, where the aim is to gain knowledge about the sanitation situation in Yasmine informal settlement. In the end of this semester, I will come up with possible solutions for an improved system and try to design a sustainable sanitation system for you.

Throughout the interviews I want to learn more about people's practices, preferences and awareness surrounding wastewater and sanitation. As part of the questions I would like to see your household's water and sanitation facilities, and in addition to the questions I ask, I will take notes about the facilities you show me.

Your household has been chosen for the interview by random selection and only a certain number of households in this camp will be interviewed. The purpose is to obtain a general view of the situation and all the information you give remains strictly confidential.

The interview will take about 20 minutes (about 18 questions).

**Q1**. Would you agree to participate in the interview?

A. Yes (ask for details below) B. No

| | |
|---|---|
| Name | |
| Sex | |
| Age | |
| Education level | |
| Occupation | |

## HOUSEHOLD CHARACTERISTICS

**Q2.** Are you the head of the household?

A. Yes
B. No
C. N/C

**Q3.** How many adults (aged 15 years and above) live in this household permanently including you? *F/M*

........................................................................................................................................................

**Q4**. What is the education level and occupation for the other adults in this household?

........................................................................................................................................................

**Q5.** How many children (5-14 years) live in this household? *F/M*

.....................................................................................................................................................................

**Q6.** How many infants (0-4 years) live in this household? *F/M*

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**Q7.** What is the average total monthly income of the household? This includes income earned by all members of the household and all sources (income from employment, own production, received from other family members etc.)

.....................................................................................................................................................................

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## SANITATION AND HYGIENE

**Q8**. Are you satisfied with the water and sanitation situation you have today? Why/Why not?

.....................................................................................................................................................................

.....................................................................................................................................................................

.....................................................................................................................................................................

**Q9**. Did you receive any hygiene and sanitation training, and got familiar with the construction and use of toilet when the new system was built?

A. Yes B. No

**Q10**. How would you rate the quality of the toilet you use on a scale from 1=poor to 6=good?

| | *Poor* | | *Acceptable* | | *Good* | | *N/C* |
|---|---|---|---|---|---|---|---|
| A. Effective operation (no leakage, no overflow, no blockage) | 1 | 2 | 3 | 4 | 5 | 6 | 0 |
| B. Facilities (soap for handwashing, bin/bag for disposal etc) | 1 | 2 | 3 | 4 | 5 | 6 | 0 |
| C. Odor | 1 | 2 | 3 | 4 | 5 | 6 | 0 |
| D. Protection and safety | 1 | 2 | 3 | 4 | 5 | 6 | 0 |
| E. Easy to use and keep clean | 1 | 2 | 3 | 4 | 5 | 6 | 0 |

**Q11.** Are there any problems with the toilet you use?

……………………………………………………………………………………………………………………………………

……………………………………………………………………………………………………………………………………

……………………………………………………………………………………………………………………………………

……………………………………………………………………………………………………………………………………

**Q12.** What kind of toilet do you prefer?

A. Squat
B. Sit

What type?

A. Dry toilet
B. Flush toilet
    a. Poor-flush (with bucket)
    b. Button-flush (European/Western style)
C. Pit latrine
D. EcoSan toilet (Vermicomposting: Possibility to get crops/plant to grow)
E. Open defecation

**Q13.** How much does your household approximately spend per year for repair and cleaning of the toilet?

……………………………………………………………………………………………………………………………………

………………………………………………………………………………………………LBP……………………………………

*1500 LBP = 1 USD*

**Q14**. Are you willing to pay for an improved system, and in that case; how much?

……………………………………………………………………………………………………………………………………

……………………………………………………………………………………………………………………………………

**Q15**. I would very much like to see your toilet – would you kindly show it to me?

A. Yes B. No

***Q16.*** *Observation about the toilet:*

A. *Visible fecal residues in and around the drop whole or the basin*
B. *Visible fecal residues on the floor, wall or door*
C. *Surface flow of sewage*
D. *Bad smell*
E. *Flies and other insects*
F. *Available soap for hand-washing*
G. *Available anal cleansing material (toilet paper etc)*
H. *Available cleaning items (detergents, brush etc)*
I. *Menstrual hygiene materials*
J. *Bin/bag for disposal*
K. *Lighting*
L. *Lock on the door*
M. *Windows*
N. *Ventilation chimney*
O. *Roof*
P. *Bulking materials*
Q. *Other observation:*

---

## WILLINGNESS AND POSSIBILITIES FOR A SUSTAINABLE SYSTEM

1. *The sanitation system today separates the wastewater into one fraction for GW (laundry, shower, kitchen) and one fraction for BW (toilet). To save some of the water, one opportunity is to reuse the greywater after a simple treatment.*

   Are you willing to reuse the greywater for irrigation purposes and watering trees, bushes and non-edible plants?

2. *The toilets you have here today could easily be upgraded to a more environmental solution with advantages for the householder owners. One option is to design a storage area under the toilet where the contents become fertile soil after a while. This process is more efficient with a vermicomposting toilet where organic material is consumed by worms. This will give a nutrient-rich compost that are easily absorbed by the roots of your plants.*

   Are you willing to use an ecological sanitation type of toilet, in advantage to get a nutrient-rich fertilizer for your plants/gardening?

3. *The urine in human excreta is very nutrient rich and could be collected in a removable container and used as fertilizer after a while. Studies has shown that safe use of human urine as a fertilizer will increase the production, and there is possible to spend less money compared to the use of chemical fertilizer.*

   Are you willing to use human urine as a fertilizer?

4. *Waste from animal manure, crop waste, garden waste and kitchen waste could be used to produce biogas. If the toilets get connected to a biogas reactor, the biogas production will increase, as well as the produced energy that could be used for cooking. During the biogas production, pathogens are reduced, and sludge is produced that can be used as fertilizer.*

   Are you willing to use biogas for cooking and the produced sludge as a fertilizer?

Do you have any further questions or comments?

..............................................................................................................................................................

Thank you very much for your time and information, and feel free to contact me again

---

End time:

| | | | |
|---|---|---|---|
| | | | |

## APPENDIX IV: TOPIC GUIDE FOR FOCUS GROUP DISCUSSIONS

1. Advantages with the wastewater- and sanitation system today
2. Disadvantages with the wastewater- and sanitation system
3. Does the system need to be upgraded? Why and how can it be upgraded?
4. The system could be upgraded in many ways and provide different advantages. (Show pictures and explain options like 1) Receive electricity e.g. collect urine to produce energy from microbial fuel cells or produce biogas from sludge in a larger-scale system. The energy can be used to light up the toilets, charge phones, cook or heat up the household, 2) Use the human excreta as a resource and reuse it as a fertilizer on crops or plants for gardening purpose, e.g. urine diversion- or vermicomposting toilets, 3) Water saving and reuse treated greywater for flushing, gardening purposes or laundry washing to save some water.

- What is your biggest need and desire?

## APPENDIX V: MESUREMENTS FROM INFILTRATION TESTS

Site 1 (Ø 22cm, depth 12cm):

| Time [min] | Height [cm] | Water level drop [cm] |
|---|---|---|
| 0 | 5 | 0 |
| 1 | 4.6 | -0.4 |
| 2 | 4 | -0.6 |
| 3 | 3.5 | -0.5 |
| 4 | 3.3 | -0.2 |
| 5 | 3 | -0.3 |
| 6 | 2.8 | -0.2 |
| 7 | 2.5 | -0.3 |
| 8 | 2.4 | -0.1 |
| 9 | 2 | -0.4 |
| 10 | 1.9 | -0.1 |
| 15 | 1.3 | -0.6 |
| 20 | 0.5 | -0.8 |
| **23** | **0** | -0.5 |

Site 2 (Ø 45cm, depth 60cm):

| Time [min] | Height [cm] | Water level drop [cm] |
|---|---|---|
| 0 | 17 | 0 |
| 1 | 16 | -1 |
| 2 | 15 | -1 |
| 3 | 14 | -1 |
| 4 | 13.7 | -0.3 |
| 5 | 13.4 | -0.3 |
| 6 | 13.3 | -0.1 |
| 7 | 13.1 | -0.2 |
| 8 | 13 | -0.1 |
| 9 | 12.8 | -0.2 |
| 10 | 12.5 | -0.3 |
| 15 | 12.1 | -0.4 |
| 20 | 11.5 | -0.6 |
| 25 | 11 | -0.5 |
| 30 | 9.9 | -1.1 |
| 35 | 9.5 | -0.4 |
| 40 | 9.1 | -0.4 |
| 45 | 8.7 | -0.4 |
| 50 | 8.3 | -0.4 |
| 55 | 7.8 | -0.5 |
| 60 | 7.2 | -0.6 |
| 70 | 6.2 | -1 |
| 80 | 5.6 | -0.6 |
| 90 | 4.2 | -1.4 |
| 100 | 3.3 | -0.9 |
| 110 | 2.5 | -0.8 |
| 120 | 1.8 | -0.7 |
| 130 | 1.3 | -0.5 |
| 140 | 0.9 | -0.4 |
| 150 | 0.5 | -0.4 |
| 160 | 0.1 | -0.4 |
| **162** | **0** | -0.1 |

Site 3 (Ø 30 cm, depth 40 cm):

| Time [min] | Height [cm] | Water level drop [cm] |
|---|---|---|
| 0 | 9 | 0 |
| 1 | 8 | -1 |
| 2 | 7.6 | -0.4 |
| 3 | 7 | -0.6 |
| 4 | 6.9 | -0.1 |
| 5 | 6.5 | -0.4 |
| 6 | 6.3 | -0.2 |
| 7 | 6.2 | -0.1 |
| 8 | 6 | -0.2 |
| 9 | 5.9 | -0.1 |
| 10 | 5.8 | -0.1 |
| 15 | 5.2 | -0.6 |
| 20 | 4.8 | -0.4 |
| 25 | 4.2 | -0.6 |
| 30 | 3.5 | -0.7 |
| 35 | 2.9 | -0.6 |
| 40 | 2 | -0.9 |
| 45 | 1.3 | -0.7 |
| 50 | 0.6 | -0.7 |
| **54** | **0** | -0.6 |

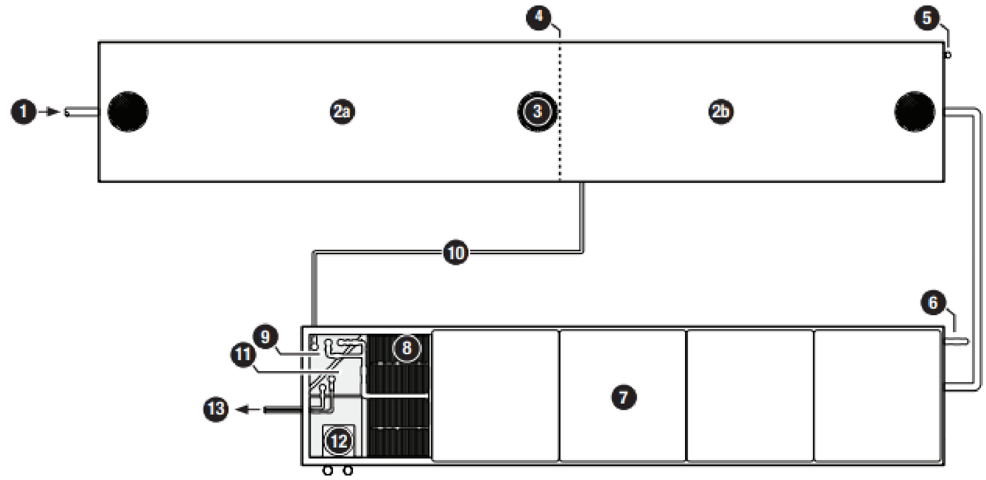
## APPENDIX VI: TECHNICAL DRAWING AND DESIGN CRITERIA – ADVANTEX AX-MOBILE SYSTEM

**Design Criteria** Orenco SYSTEMS

### AdvanTex AX-Max™

AX-Max Specifications:

| | |
|---|---|
| Length | 14-42 ft (4.2-12.8 m) |
| Width | 90 inches (2286 mm) |
| Height | 97 inches (2464 mm) |
| Dry weight | Variable, up to 12,000 lbs (5440 kg) |
| Treatment surface area | 25-300 $ft^2$ (2.3-27.9 $m^2$), nominal |
| Installation footprint | 112-336 $ft^2$ (10.4-31.2 $m^2$), actual |
| Installation methods | Partial burial or bermed installation, or free-standing installation; 24-36 inches (610-910 mm) above grade or berm for ease of maintenance; antifloatation available for areas with high groundwater |
| Recirculation-blend tankage | Included |
| Recirculation method | Tank baffle wall, recirc-return valve |




1. Raw sewage inlet to primary tankage
2. 42-ft (12.8-m) Orenco® T-Max™ Tank:
   a) primary tankage
   b) pre-anoxic tankage
3. Effluent filter
4. Baffle wall
5. Passive primary tank ventilation
6. Vent fan inlet
7. Secondary treatment: 35-ft (10.7-m) AX-Max™ Unit
8. AX-Max Unit: treatment media
9. AX-Max Unit: recirc-blend and pre-anoxic pumping chamber
10. Pre-anoxic return line
11. AX-Max Unit: discharge pumping chamber
12. AX-Max Unit: active ventilation system
13. Discharge to dispersal or tertiary treatment process

Figure 3. Example of an AdvanTex AX-Max Commercial Treatment System

V1
04/04/2016

# ECOROCK-5000

## Treatment Unit
## Tank volume 5000 L

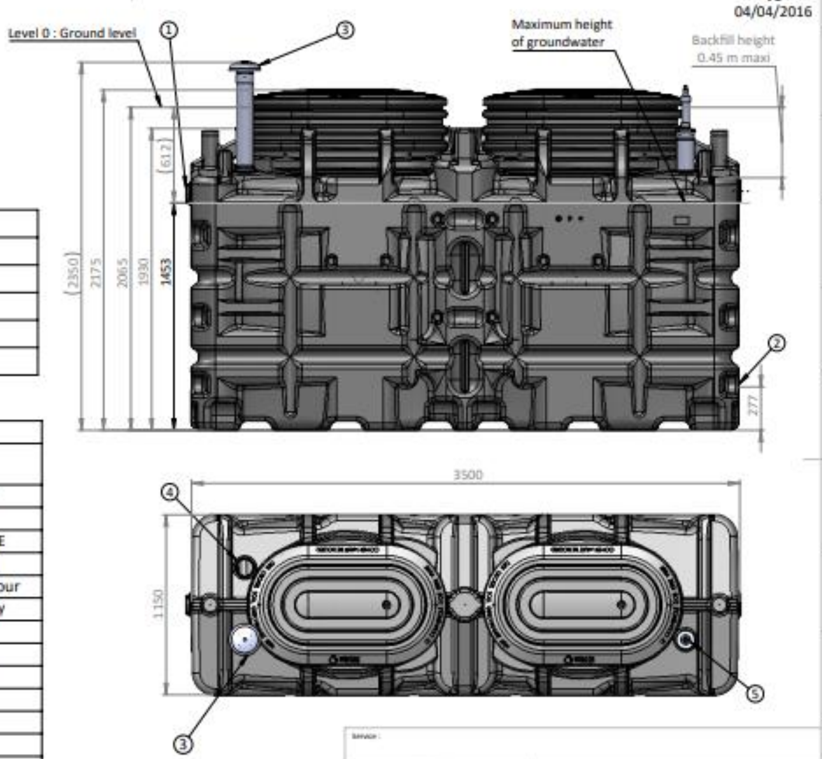
| | |
|---|---|
| 1 | Water inlet |
| 2 | Water outlet |
| 3 | Air inlet |
| 4 | Air outlet |
| 5 | Overflow Alarm |

| Characteristics | Value | Unit |
|---|---|---|
| **ECOROCK-5000 Treatment Unit** | | |
| Minimum volume pre-treatment* | 500 | liters/PE |
| Capacity in population equivalent | 30 | PE |
| Daily volume of wastewater ** | 150 | litres/day/PE |
| Daily hydraulic load | 4.5 | $m^3$/day |
| Organic load per PE | 60 | gr.$BOD_5$/PE/jour |
| Organic load raw influent up to | 1.8 | kg $BOD_5$/day |

| Specification | Value | Unit |
|---|---|---|
| Tank volume | 5000 | Liters |
| Overall length | 3500 | mm |
| Overall width | 1150 | mm |
| Total height of the tank | 2175 | mm |
| Overall height (+ventilation pipe) | 2350 | mm |
| Total weight (without water) | 680 | Kg |
| Pipe diameter | 110 | mm |

This treatment unit can be installed in high ground water table.

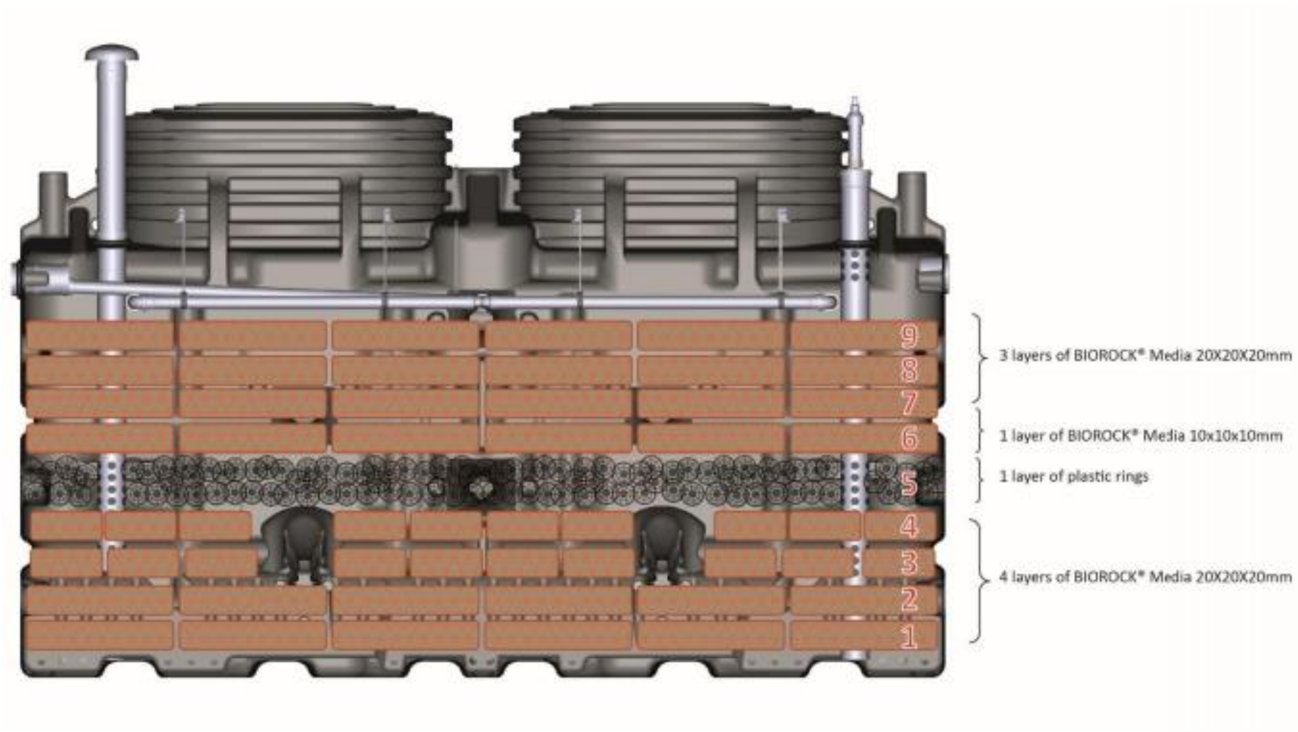
*minimum 2000 liters of pre-treatment
**according to DIN EN 12566-3

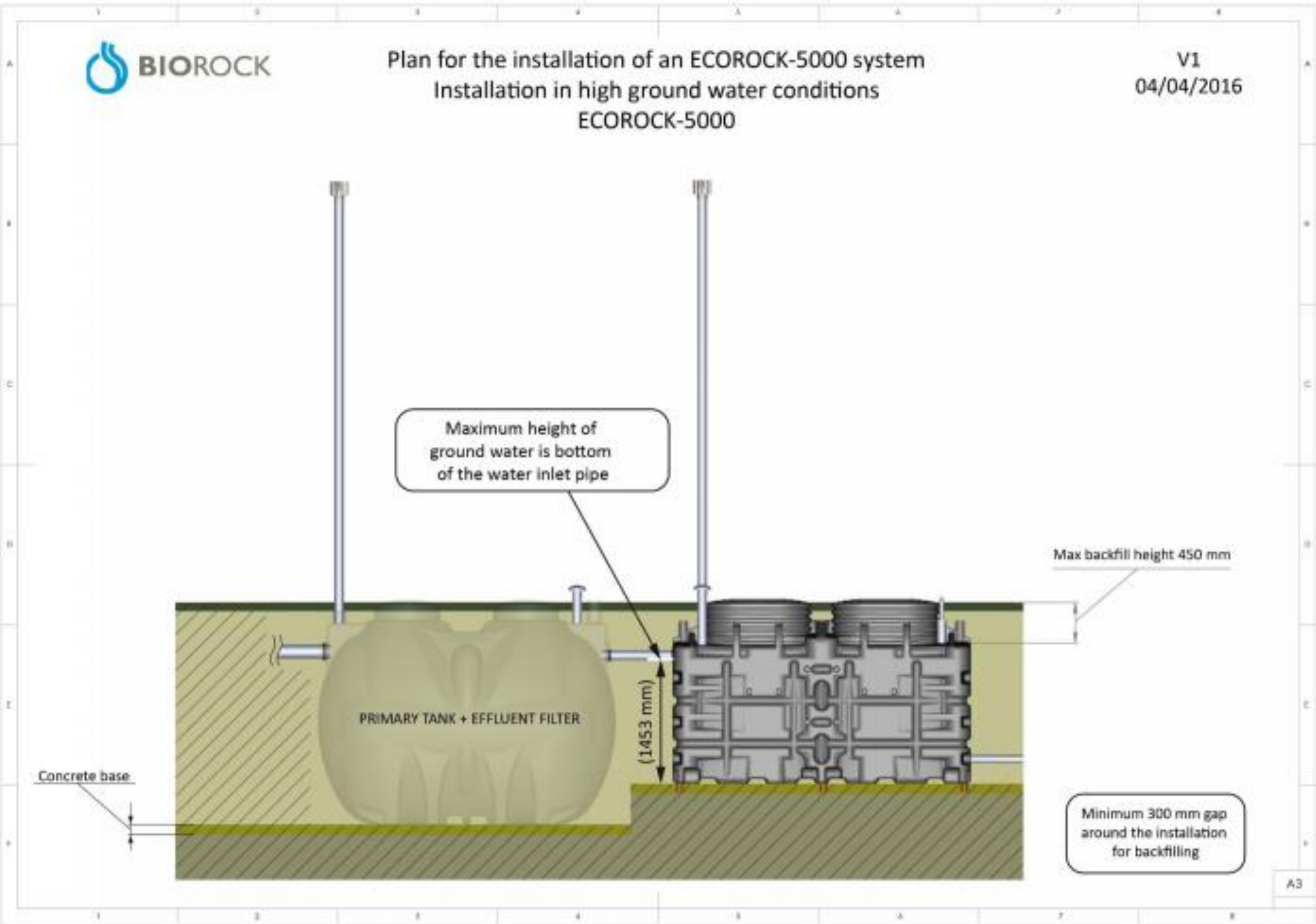



Overall tolerance : 3%

BIOROCK
ECOROCK-5000
AUTHOR AQ 04/04/2016
UT-X5000

Drawing (Cross section) showing the layers of BIOROCK® Media in a ECOROCK-5000 unit



# APPENDIX VIII: BIOGAS POTENTIAL

| Potential biogas production: |
|---|
| The amount of methane produced depends on the rate of removed COD, temperature, content of dry matter/organic dry matter and type of biogas sanitation system.<br>0.350 $m^3$ $CH_4$/kg COD removed; or 1 kg BOD removed results in the production of 0.35 $m^3$ methane at 273° K and p=po; energy content of methane = 35.8 MJ/$m^3$. If the production of blackwater and organic waste is 100 g BOD/person/day, this results in 35 L methane/person/day (Zeeman et al., 2006).<br>According to International Comitee of the Red Cross (ICRC) it is possible to produce 27 L biogas per person per day from faeces under operational temperatures of 26-30 ° C, with a methane content ranging from 57 % to 78 % (ICRS, 2009).<br>According to (Jekel et al., 2006) it is possible to produce 0.450 $m^3$ biogas/kg ODM or 0.290 $m^3$ methane/kg ODM (0.210 kg methane/kg ODM).<br>1 $m^3$ of biomethane can generate 9.94 KWh of energy (Suez, 2014) |

**An overview of the biogas sanitation systems (Mang & Li, 2010)**

| Type of digester | Expected BOD reduction [%] | HRT | OLR [kg COD/$m^3$] | SRT | Optimal application |
|---|---|---|---|---|---|
| Biogas septic tank (BST)/Biogas settler (BS) | 25-60 | 20-40 days | 0.5-2 | 10 days- 7 years | Pretreatment |
| Anaerobic baffled reactor (ABR) | 70-90 | 2-4 days | 1-12 | ≥ 2 years | Post-treatment after BS |
| Anaerobic filter (AF) | 50-90 | 0.5-4 days | 5-15 | Theoretical no, but sludge may accumulate at the bottom | Post-treatment after BST or ABR |
| Upflow sludge blanket (UASB) | 55-90 | 0.5-10 days | 15-32 | ≥ 1 years | Post-treatment after BS or BST, or as main treatment after grid chamber |

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