DIPLOMA THESIS

Technical Feasibility of decentralised Greywater Treatment Units to improve Sanitation in peri-urban Areas of Ulaanbaatar, Mongolia

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Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due acknowledgment has been made in the text.

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Berlin, January 9th, 2015

Abstract

Following the global development of large cities, Ulaanbaatar, capital of Mongolia, is currently facing the challenges that evolve from urbanisation. Informal settlements (‘ger areas’) are rapidly established outside the city centre. Ger area households are not connected to piped water supply or sewage systems and local residents are depending on drinking water from public water kiosks. After usage, the water is discharged into the soil, in an uncontrolled manner in form of greywater. Due to the fact that water is used several times and traditional diet contains high amounts of fat, local greywater is heavily polluted (COD up to 12,144 mg/l, E.coli up to $2.1*10^6$ CFU/100ml). The lack of sewage systems is leading to high rates of water borne diseases, such as diarrhea or Hepatitis A. To face these challenges, two different greywater pilot systems are developed and constructed in the context of this research work. Their set-up and operation are specifically based upon high pollution levels of the greywater and extreme local climate conditions (temperatures drop below -40°C). The low-tech small-scale treatment units consist of multiple purification steps and are designed to achieve effluent values meeting irrigation standards. First laboratory analyses indicate satisfying and steady results and therefore demonstrate the technical feasibility of greywater treatment units in the research field.

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Abbreviations

ACF	Action Contre la Faim (Action against Hunger)
Aimag	Mongolian Province
BOD	Biological Oxygen Demand
Cl^-	Chloride
COD	Chemical Oxygen Demand
CSES	Centre for Sustainable Environmental Sanitation at the University of Science and Technologies of Beijing (China)
CW	Constructed Wetland
DOC	Dissolved Organic Carbon
Düüreg	District of Ulaanbaatar
E.coli	Escherichia Coli
FAO	Food and Agricultural Organisation
FOG	Fat, Oil, Grease
Ger	Mongolian yurt
GH	Greenhouse
GHTU	Greenhouse Treatment Unit
GW	Greywater
GWTU	Greywater Treatment Unit
IBU	Ice Block Unit
IGHU	Inside Greenhouse Unit
Khoroo	Sub-district of Ulaanbaatar
MO	Microorganism
MoMo	Integrated Water Resources Management Project in Central Asia: Model Region Mongolia
N	Nitrogen
NH_4	Ammonia
NO_3	Nitrate
NO_2	Nitrite
NGO	Non-Governmental Organization
P	Phosphorous
PO_4	Phosphate

RF	Roughing Filter
Schmutzdecke	Biofilm that develops in the upper layer of the slow sand filter
SSF	Slow Sand Filter
ST	Septic Tank
T	Temperature
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UB	Ulaanbaatar
UFRF	Upflow Roughing Filter
UFZ	Umweltforschungszentrum – Helmholtz Centre for Environmental Research
UGTU	Underground Treatment Unit
USEPA	U.S. Environmental Protection Agency
USTB	University of Science and Technologies of Beijing, China
USUG	Water Supply and Sewerage Authority of Ulaanbaatar City
VF	Vertical Flow
VFB	Vertical Flow Bed
VFCW	Vertical Flow Constructed Wetland
WaSH	Water Sanitation and Hygiene
WHO	World Health Organisation
WWTP	Wastewater Treatment Plant
Zhud	Harsh weather situation with extremely cold winter and summer droughts

1 Introduction

Figure 1: Ulaanbaatar‘s ger area with children collecting water from a water kiosk (top) and a typical compound (bottom) (ACF, 2013).

Mongolia’s economy is developing rapidly and as a result of growing industrial- and agricultural sectors the country’s water consumption has increased in recent years (UNDP, 2010; FAO, 2014). In contrast, changing climate conditions are leading to water shortages as precipitation has decreased during the summer affecting stream flows and seasonal run offs (Batimaa, 2011). Only since 2003 the number of dried up streams, lakes and springs has risen by 30% creating water scarcities in many areas (UN-Water, 2012). Furthermore the country experienced an increasing series of so-called “zhuds”, (seasons with summer droughts and extreme cold winters over the last years) which raises difficulties of performing the traditional nomadic culture (World Bank, 2010). Additionally favoured by these circumstances, Mongolia currently experiences a transformation from nomadic to settler life-style which is indicated in a rapid urbanisation. Today the urban population already accounts to 68.5% of the total population (CIA, 2014) with almost half of the countries residents living in Ulaanbaatar (UB), the capital of the country (World Bank 2010).

In UB, new informal peri-urban settlements (‘ger areas’) are established outside of the city (see Figure 1). In 2012 over 60% of the capital's residents lived in these low income settlements that severely lack of basic infrastructure and adequate sanitation (Sigel, 2012). As piped freshwater distribution is not area-widely supplied, the great majority of ger area residents manually collect it from water kiosks (World Bank, 2010). This inconvenient practice is leading to low average water consumption with 8-10 litres per capita per day during the summer months. In winter it can drop down to 4 litres per capita per day (Uddin, 2014a) whereas the consumption in the centrally supplied city centre ranges between 240-450 litres per capita per day (Dore, 2006).

In terms of disposal it is common practice to discharge wastewater in simply detached pit latrines and soak pits or in the streets in front of the compound (Uddin, 2014a). The absence of appropriate water distribution systems and sanitation results in soil and groundwater pollution and downgrades the health of the local population. Morbidity patterns in these settlements demonstrate high values of waterborne diseases, especially those that are promoted by poor environmental living conditions (e.g. diarrhoea or Hepatitis A) (Sigel, 2011). The rate of Hepatitis A is seven times higher than the international average (GIZ, 2008). To improve the sanitary situation by connecting the ger areas to the central water distribution system is argued to be unfeasible due to unsolvable financial challenges (World Bank, 2010; Ulrich, 2010). As the status quo of water distribution in the ger districts appears to remain in the future, decentralised treatment options provide suitable approaches in order to address the sanitary challenges.

In the interest of contributing to an improvement of sanitation and to mitigate water shortages, this study aims to assess the feasibility of decentralised Greywater Treatment Units (GWTUs) in the ger area. Greywater (GW) is a separate stream of wastewater and consists of effluents from kitchen, laundry and bathroom. Even though that GW is considered to be the least polluted of all streams (Li, 2009) it can contain high amounts of pollutants and therefore cause negative impacts on environment and health if discharged unplanned (Friedler, 2004; Gross, 2006). GW from ger districts is heavier polluted than in most other countries (e.g. COD up to 12,144 mg/l, E.coli up to 2,100,000 CFU/100ml (own data, 2013; USTB, 2010)) which implies the necessity to adjust treatment systems accordingly. In addition to considering the specific composition the treatment technologies are designed for the extreme climate conditions occurring in the coldest capital of the world with temperatures dropping below -40°C (World Bank, 2014).

In 2010 two GWTUs were implemented in the ger area but failed shortly after initiation. In the context of this research the previous units were evaluated in terms of their technological and their conceptual shortcomings. Based on lesson learnt improved designs were elaborated during winter 2012/2013 and two new and upgraded GWTUs were installed in summer 2013; the Greenhouse Treatment Unit (GHTU) and the Ice Block Unit (IBU). Both systems mainly apply physical and biological processes and purify greywater with multiple stage treatment steps. The treatment units aim to achieve quality standards that allow irrigation on the private compound, respectively GW could be used as water source. The treatment steps and technologies applied are described in detail and designs and flow charts are provided in this thesis. To determine the performance of the GWTUs samples are conducted and results are discussed. To allow sustainable functioning user guidelines and maintenance/monitoring manuals are developed.

The purpose of this study is to **(1)** determine the technical feasibility of low-tech, economically sound and simple-maintenance GWTUs in the ger area under consideration of extremely cold climate conditions and heavy pollution of greywater. **(2)** To find out if the systems are capable to treat greywater to standards suitable for irrigation. If treatment units prove to be suitable they can decrease the negative impacts resulting from uncontrolled greywater discharge and mitigate the water stress in the research area.

2 Mongolia - Geography, Population, Climate and Water Situation

2.1 General Aspects

Mongolia is unique country in many ways and requires extensive observations to recognise the particular background of this study. To provide a better understanding of the local circumstances of this research, the following subchapters present background information on the geography, the population, the climate and the water situation in Mongolia. The specific research field, the peri-urban districts of Ulaanbaatar, are introduced under more detailed consideration.

2.2 Geography and Population

Mongolia is located in the middle of the central Asian plateau and with an area of about 1.56 million km^2 it is the world's 19th-largest country (Batimaa, 2011). As a landlocked country it is bordered in the north by Russia while all three other geographic directions are surrounded by China (see Figure 2 & Figure 3). Mongolia lies between longitudes of around 87° and 120° and latitudes between 41° and 52° (USTB, 2010). The northernmost area lies on related latitude as Berlin, the southernmost area is on similar latitude with Rome. The westernmost terrain lies on a related longitude as Kolkata, the eastern area is on a similar longitude as the west of Taiwan.

Figure 2: Visualization of the location of Mongolia (Wanttoknowit, 2014).

The geography of the country varies with mountains located in the north, west and south-west and the Gobi desert in the south central area. Most of the terrain is vast semi desert and desert plains or grassy steppe. Pastures and arid grazing cover around 80% of the land area, around 10% is forest area and only 0.5% of Mongolia's total area is arable. The rest is used by e.g. settlements or national parks (FAO, 2014). The country is comparably high elevated with the lowest point at 560m (Hoh Nuur) and its highest point at 4374m (Huyten Orgil) (CIA, 2014).

Administratively the country is divided into 21 provinces (‘aimags’) and each aimag is provided with a provincial capital and a local government. The biggest city and capital is Ulaanbaatar (also see Chapter 2.4). Even though Mongolia's population has more than doubled since 1960, its density remains one of the lowest in the world (1.8 people per km^2, (UNDATA, 2014)). Today its total population is 2,953,190 (CIA, 2014). Mongolia currently undergoes a rapid urbanisation with an annual rate of change of 2.81%. Today the urban population already accounts for 68.5% of the total population (CIA, 2014) with almost half of the countries residents living in Ulaanbaatar (World Bank 2010). Reasons for that are broad, but mostly based on changed climate conditions and/or the transition of the country to a market economy. With 45.5% of the country's population under 25 years (CIA, 2014), families seek better education and higher economic standards for young people when moving to urban areas. Furthermore the country experienced an increasing series of so-called “zhuds”, with summer droughts and extreme cold winters, over the last years. The results of changing climate in Mongolia, e.g. desertification and increasing snowfall during the winter months, are causing increasing challenges for animals in terms of finding food (USTB, 2010). Life in the steppe is depended on livestock and with changing climate conditions it becomes more difficult to pursue the traditional nomadic life style. In a consequence the country experiences a massive transformation from nomadic to settler life style.

Figure 3: Map of Mongolia with surrounding countries (CIA, 2014).

2.3 Climate Conditions and Water Situation

Mongolia has an arid and extreme continental climate with long and very cold winters and short summers. The country experiences a wide seasonal range of both temperatures and precipitation, which is visualised in Figure 4. During the winter months from November until April, the average temperature ranges around -14°C and also extreme temperatures occur with less than minus 40°C (World Bank, 2014).

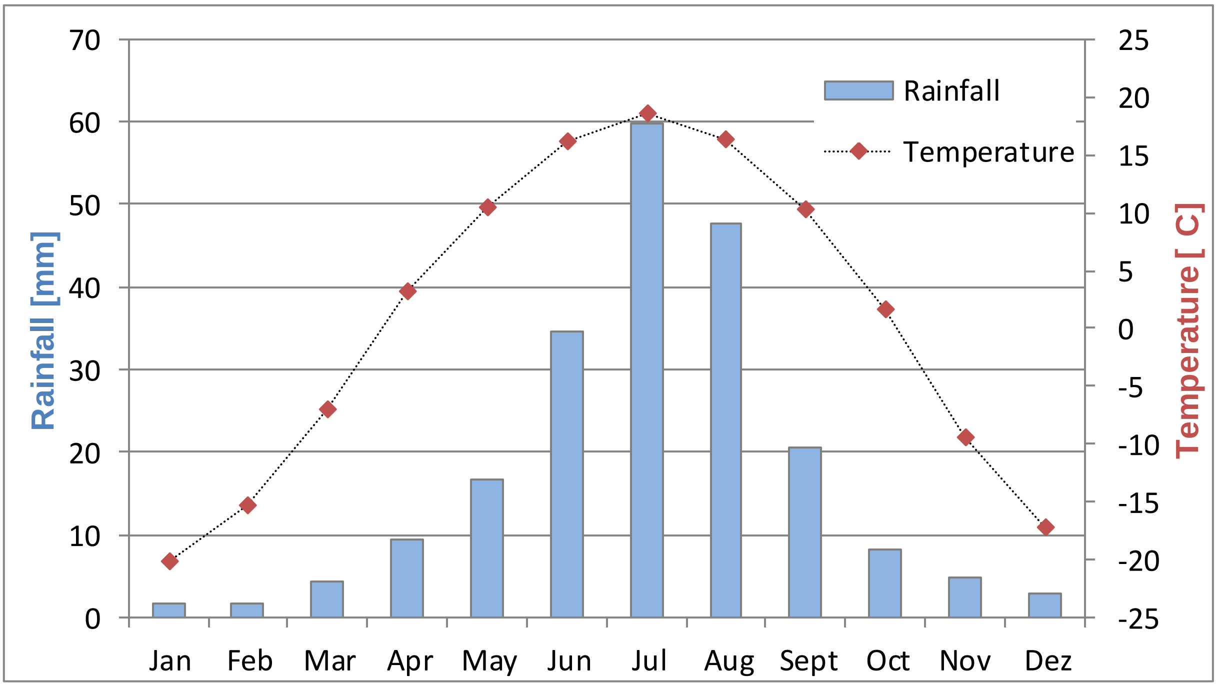


Figure 4: Average monthly temperature and rainfall in Mongolia from 1990-2009 (modified by World Bank, 2014).

The summer months are short but bring high temperatures and most of the annual precipitation. In some cases, like the Gobi desert, temperatures can reach up to 40°C. The average annual precipitation is low and ranges around 241mm (UN-Water, 2012), whereas in e.g. Germany it ranges around 700mm (World Bank, 2014). Changing climate conditions is a growing concern in Mongolia. Average monthly temperatures increased by 3.6°C during winter over the last 70 years with more snowfall during these months. Additionally precipitation decreased during summer whereby, stream flows and seasonal run offs are affected. The results are e.g. longer dry periods in the low flow season leading to water shortages (Batimaa, 2011). The consequences of this trend are already detectable. Only since 2003 the number of dried up streams, lakes and springs has risen by 30% which is creating challenges of limited natural fresh water resources in certain areas (UN-Water, 2012).

The total water consumption of Mongolia today is about 0.55km^3 per year which accounts to roughly 197m^3 per capita per year. The withdrawal has risen over the last years, data from 1996 indicate that total consumption that year was around 0.4km^3 (FAO, 2014). Roughly 87% of the fresh water is used by agriculture and industry, the remaining 13% is for domestic usage (CIA, 2014). About 80% of total water withdrawal is contributed by groundwater resources and 20% by surface water resources (Batimaa, 2011). Mongolia’s long-term average annual internal renewable water resources (IRWR) are 34.8km^3 (UN-Water, 2014).

The infrastructure of water distribution systems is not broadly developed in Mongolia, only 30.7% of the residents are connected to a water supply network. The centralised systems in urban areas however, were established in the 1980s and partly show deficient conditions since they are not accordingly maintained. The majority of the population acquires water independently through e.g. own wells, or receive it from public water kiosks. In 2006 only just over 50% of the households had clean access to drinking water (Batimaa, 2011). In addition 3.5% WaSH-related (Water, Sanitation and Hygiene) deaths of total deaths indicate a poor development in that sector (UN-Water, 2014). The situation is especially severe in Mongolia’s rapidly growing peri-urban areas, such as the outskirts of Ulaanbaatar. The following chapter provides further information about the capital with a focus on its water situation.

2.4 Ulaanbaatar and its Ger Areas

Ulaanbaatar (UB) is Mongolia's cultural, governmental and economical centre with a population of about 1.2 million (Baasankhu, 2012). It is located in the northeast central of Mongolia (see Figure 3) and lies at an altitude of about 1310m. Like the rest of the country, the city has extreme continental climate with very cold and long winters. UB is the coldest capital in the world, average temperatures in January reach around -26°C and in individual cases they can drop below -40°C (World Bank, 2014). Winter usually lasts from November until late April, the warmest month is July with average temperatures around 17°C and highest values reaching 39°C. The average annual precipitation is 240mm and most of the rain falls during summer (USTB, 2010). The city is located in a valley with a mountainous part in the north and the Tuul River in the south. The capital is its own administrative unit and no member of the aimags. It is divided into nine districts ('düüregs'), which are again subdivided into 121 sub districts ('khoroos'). UB's city centre is built in 1950s Soviet-style architecture with relatively modern apartments. The central area's infrastructure is adequately developed with public services, sanitation systems and central heating.

The rapid urbanisation of Mongolia is very well indicated in the fast growing population of UB. From about 600,000 people living there in the late 1980s, today almost half of the countries residents are populating the capital (World Bank, 2010). Unlike the rest of the country UB is relatively densely populated. Most of the people moving from the countryside to the city move to the outskirts of UB. New informal settlements (peri-urban areas) are established outside of the city. In 2012 already over 60% of the capital's residents lived in these low income settlements where living standards vary greatly from those in the modern and developed centre of UB (also see Chapter 2.4.2) (Sigel, 2012).

2.4.1 Water Distribution in the City Centre of Ulaanbaatar

The city centre of UB is supplied by a central water distribution network. The most important fresh water resource for UB is the Tuul River. The river feeds the aquifer that provides the city with most of its water. Over the last years the Tuul River resources have lowered considerably, compared to values from the mid-1990s they are less than one third. Projections assume an on-going decrease of these resources with at least 2% in 2020 (Batimaa, 2011). Predominant reasons are decreased precipitation in the upper river and increased water demand by the city. As current numbers indicate, Mongolia's capital is facing severe challenges in water scarcity in the future (UNDP, 2010).

Freshwater supply is provided by two separate mechanisms in UB. On one hand, in the city centre, modern apartment buildings are connected to a central water system and water is supplied to each individual household. Around 350km of distribution pipelines provide water from wells around the Tuul River and pumping stations to the centre (Batimaa, 2011). 147km of sewer networks collect the sewage of residents to discharge it to the wastewater treatment plant (WWTP) west of the capital (UN-Habitat, 2010).

On the other hand, in peri-urban settlements outside the city centre, households are not connected to a piped system at all. As a consequence there is a massive discrepancy between the water consumption in the centre, compared to the districts with no connection to the central network. In 2006 the daily water usage per capita in modern apartments in UB was 291.3 litres. In the ger districts it was 7.3 litres which represents only 2.5% of the value in the centre. The differences over the years before are even higher (UNEP, 2007) and more recent data confirm that range (World Bank, 2010). More detailed information about the situation of water distribution in these areas is presented in the following chapter.

2.4.2 Ulaanbaatar's Ger Areas

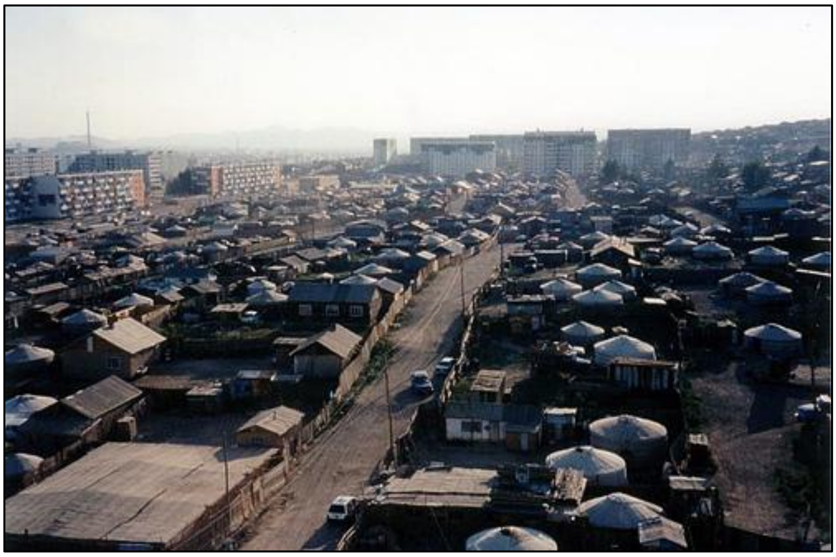


Figure 5: Ger-district as informal settlement in Ulaanbaatar (Kivafellows, 2014).

In a Mongolian context, peri-urban areas are referred to as ‘ger areas’. These districts have great significance for the capital with an administrative area that is 35 times larger than the actual city centre and where over 60% of the capital’s total population are living (World Bank, 2010). In these unplanned suburban districts people live in gers (Mongolian yurt) or simply constructed houses. Figure 5 shows a typical ger district in UB. The fast growing neighbourhoods severely lack of basic infrastructure and services, such as piped water distribution systems, paved roads, waste collection, area-wide power grid, central heating systems, adequate sanitation and other public services. Various challenges evolve from the ger areas, such as unemployment, air pollution and adheres environmental impacts (World Bank, 2010). The absence of appropriate water distribution systems and sanitation results in groundwater- and soil pollution and downgrades the health of the population. Morbidity patterns in these settlements show high values in waterborne diseases and those that that are promoted by poor environmental living conditions (e.g. diarrhoea or Hepatitis A) (Sigel, 2011). The current average water consumption is 8-10 litres per capita per day during summer months, in winter it can drop down to 4 litres per capita and day (Uddin, 2014b). This is significantly less than the 20 litres recommended by the World Health Organisation (WHO) that assure basic hygiene needs and basic food hygiene (WHO, 2014a). In addition to the poor sanitation situation in the area almost 85% of the people in these districts use coal or wood-burning ovens for heating. This creates severe air pollution for the whole city, especially in winter. In contrast, apartment houses in the city centre are provided by central heating.

2.4.3 Drinking Water Supply in the Ger Areas

Figure 6: Ger-area residents collecting water from a water kiosk (top) and transporting it with a typical cart on an icy road (bottom) (IFRC, 2014; BP.blogspot, 2014).

Ger areas are not connected to the central water system of the city centre consequently people have to get drinking water in different ways. The great majority manually collects it from water kiosk, (see Figure 6) the rest from water tanks that are supplied by trucks, or they receive it through private boreholes. Roughly 75% of the people use carts and containers to transport the water to their compounds, only 2% use vehicles (World Bank, 2010). Roads in the ger area can be steep, rocky, covered in ice or possibly do not exist which makes water transport difficult. Extreme cold temperatures and speeding traffic can be further obstacles. Roughly half of the kiosks are connected to a distribution system the rest is supplied by tanker trucks or receive water from local wells. Data from similar target region in Darkhan (3rd most populated city in northern Mongolia) indicate that availability and quality of the water from water kiosks connected to a piping system is highest (Gawel, 2011). However, water quality from kiosk varies from one another and does not always meet the drinking water guidelines by the WHO. A quality analysis at household level indicates that over 50% of the water samples are contaminated by E.coli (Uddin, 2014b).

There are more than 550 water kiosks available in these districts, the great majority of them are managed by the Water Supply and Sewerage Authority of Ulaanbaatar City (USUG). Each water kiosks is located to provide about 1,000 people and reachable for most ger residents within 100-500m distance. Water from water kiosks is commonly affordable for the residents in the ger area (about \$0.71 per m^3). Water expenses account for less than 3% of household expenditures, even for low-income households (World Bank, 2010). That is mainly due to extremely low consumption, being a result of inconvenient supply. If consumption patterns change and exceed the average 8-10 litres per capita per day, it can put economic pressure on the residents of these low income areas. It is also to mention that water tariffs in the wealthier central apartment areas are much lower and represent only 28% of the price from the ger area (about \$0.2 per m^3, (World Bank, 2012)). In comparison to German rates, in e.g. Berlin (about \$2.3 per m^3 (BWB, 2014)), both rates can be considered low.

2.4.4 Wastewater Disposal and Sanitation in the Ger Areas

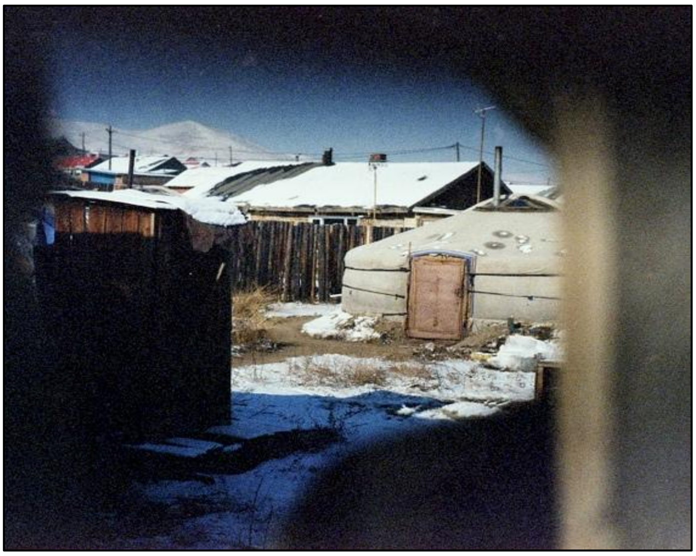


Figure 7: Typical ger area compound with a Mongolian yurt and pit latrine (left) (ACF, 2012).

In addition to the poorly developed drinking water supply there is no overall piped sewerage system in the ger districts. It is common practice to dispose wastewater (respectively greywater, see Chapter 4) in simply detached pit latrines (40%) (Figure 7) and soak pits (51%) or discharge in the streets in front of the compound (Uddin, 2014b). Defecation is performed in pit latrines (mostly simple wooden chambers with a hole in the ground) or openly. In combination with illegal dumps for solid waste disposal there is severe environmental pollution as a consequence of these actions, namely the contamination of soil and groundwater. Since groundwater levels vary from only 0.2-4m (USTB, 2010) a cycle of pollutants is likely to be established with serious health hazards resulting for the ger community. The detection of E.coli in water from water kiosks is just one indicator for that. Inadequate sanitation and the resulting environmental degradation have already led to a high transmission of WaSH-borne diseases in these areas (World Bank, 2012; Uddin, 2014b). The rate for Hepatitis A is e.g. seven times higher than the international average (GIZ, 2008).

Even though the water situation in the ger areas is unsatisfactory, fundamental improvements, which would result from connecting the districts to the central water supply and sewerage system, seem unrealistic at the moment. It is argued that the implementation would be too expensive, especially compared to current operating costs in these areas. Furthermore it would face almost unsolvable technical challenges (World Bank, 2010; Ulrich, 2010). That is mainly due to low population density with very low per capita water consumption and extremely cold winters. Intermittent and insufficient flow rates would cause clogging and freezing of the sewage connections and other operating problems. Even with rising water consumption in these areas, distribution pipes need to be laid 3-4m below ground to prevent water from freezing (World Bank, 2012). In a consequence there are currently no plans of the capital's government to expand the central system to the outskirts of UB. The status quo of the water situation stays relevant and residents will be depended on water kiosks in the future. To face these challenges, decentralised treatment options need to be elaborated and implemented in those areas. Braking up the cycle of pollutants is crucial for the wellbeing of the peri-urban community. To initiate local improvements in the WaSH, international organisations execute numerous projects. The international non-governmental organization (NGO) Action Contre la Faim (ACF) carries out various projects in that field; one of them is the research study for this paper.

3 ACF – Action Contre la Faim

ACF – Action Contre la Faim (Action Against Hunger) is a global humanitarian organization "committed to ending world hunger, works to save the lives of malnourished children while providing communities with access to safe water and sustainable solutions to hunger." (ACF, 2014)

At its current state the NGO has 5 headquarters, New York, USA; Montreal, Canada; London, UK; Paris, France and Madrid, Spain, and more than 4600 professionals worldwide. The organisation is active in over 40 countries, providing support for around 5 million individuals (ACF, 2014).

ACF-International focuses its activities on an integrated approach, where programs and projects are adapted to regional and national systems. Four main programs are applied within the missions and they can be distinguished as follows:

- **Nutrition, health and healthcare practices**, implemented for example through feeding centres for the treatment of malnourished children, with the support of medical treatment.
- **Food security and livelihoods**, where the missions provide training programs on e.g. gardening, food conservation and breeding of animals or the distribution of seeds and tools.
- **Advocacy and awareness-raising,** in case human rights are endangered, in particular when rights to nutrition are violated.
- **Water, sanitation and hygiene (WaSH)**, where projects provide access to clean water through e.g. drilling wells, or the installation of water treatment systems. Above that training programs on various related topics are provided to the local community.

Depending on the local condition, the missions focus on one or more of these aspects. The ACF mission in Afghanistan for example has programs on nutrition, WaSH and food security, whereas ACF-Mongolia has three projects focusing in the WaSH sector exclusively.

ACF – Mongolia: The mission started in 2001, is located in Ulaanbaatar and the staff consists of 23 people (ACF, 2013). The program implemented in Mongolia aims to improve the negative consequences resulting from a lack of access to safe drinking water, sanitation and hygiene (WaSH), with a focus on Ulaanbaatar's ger area. 'WaSH' is a concept used in international development programs that takes the three components, which need to be addressed together, to achieve positive impact on health: Access to clean water, adequate sanitation and appropriate hygiene education.

The mission in Mongolia runs until mid-2015 and consists of three complementary WaSH projects in the Ger-areas of Ulaanbaatar (ACF, 2013). Their goal is to strengthen all institutional levels by improving the WaSH infrastructures, both in families and schools. That is carried out firstly through technical implementations which improve access to clean water and basic sanitation systems and secondly through educational projects on hygiene in the local community. One of the projects is an about 4.5 yearlong collaboration between ACF and the University of Science and Technology of Beijing (USTB) that integrates eight Master thesis and 1 Ph.D. thesis within the mission applied research structure.

USTB/ Ph.D.-Project: - 'Sustainable Sanitation for Vulnerable Peri-Urban Population': The project initially started in 2011 and aims to achieve additional expertise and scientific contribution for ACF. Overall goal of the project is to develop and practically test a holistic, sustainable urban sanitation approach for the benefit of the most vulnerable population. Sustainable re-use oriented sanitation options are developed, built and field-tested in winter cold climates and tailored to the particular urban settings in Mongolia. The results can be recognized and disseminated within the ACF partner network and other ACF missions and possibly applied in other countries' urban context.

Scientific supervision of the project is undertaken by Professor Li Zhifu and Guest Professor Heinz-Peter Mang from the Centre for Sustainable Environmental Sanitation (CSES) which is integrated in the Department of Environmental Engineering at the USTB.

Project manager and USTB - Ph.D. student is Nazim Uddin who is in charge of eight master students, four Mongolian and four international. The results are documented in eight different master theses which will be integrated in a dissertation related to 'Eco-City Development'. To ensure an adequate processing of the various challenges the project is divided in four different topics, with two master students each:

- **Composting - human excreta collection, treatment and use**: Development of technical principles for urine diversion toilets, composting of human excreta (faeces and urine) as well as for the closed-loop oriented use of recyclates, including management systems for collection and distribution. Guidelines for replication are elaborated.
- **Social Marketing**: Development of suitable methodologies for social marketing of sustainable re-use oriented sanitation options (e. g. composting and greywater treatment).

- **Economics Aspects:** Development of economic and financial outlines for a sustainable re-use oriented sanitation supply chain and the appropriate sanitation ladder, field-tested and adjusted to achieve appropriateness in the given peri-urban context.
- **Domestic Greywater Treatment and Re-use:** Development of technical principles for household greywater re-use oriented management (treatment, collection, distribution) in theory and practice, field-tested in winter cold climates and adjusted to peri-urban settings in Mongolia. Guidelines for replication are elaborated.

This thesis focuses on the technical feasibility of greywater systems. The Mongolian master student working on the greywater topic puts her focus on the institutional level in this context. To visualise the structure of the project and its integration in the ACF missions, a systematic overlook is provided in Figure 8.

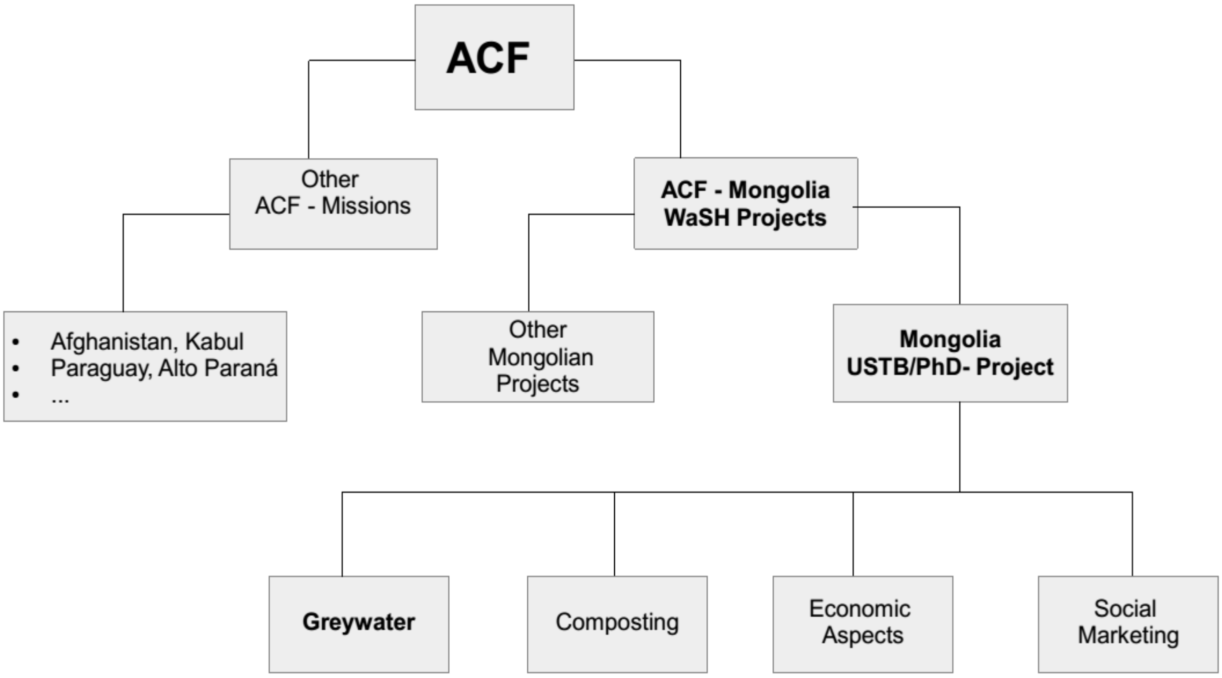


Figure 8: Visualisation of the location of this research project within the ACF structure (ACF, 2013).

4 Characteristics of Greywater with Focus on Ulaanbaatar's Ger Area

4.1 General Aspects

Greywater is one of three separate streams of domestic wastewater and is generally considered to be low contaminated (Li, 2008). However, the degree of pollution is a reflection of household activities, thus in some cases greywater can be highly polluted (Friedler, 2004; Gross, 2006). The composition of greywater is depended on various factors that need to be taken into account to apply adequate management. General characteristics of greywater and its composition in consideration of the specific local circumstances of the ger area will be discussed in the following.

4.2 Definition and Composition

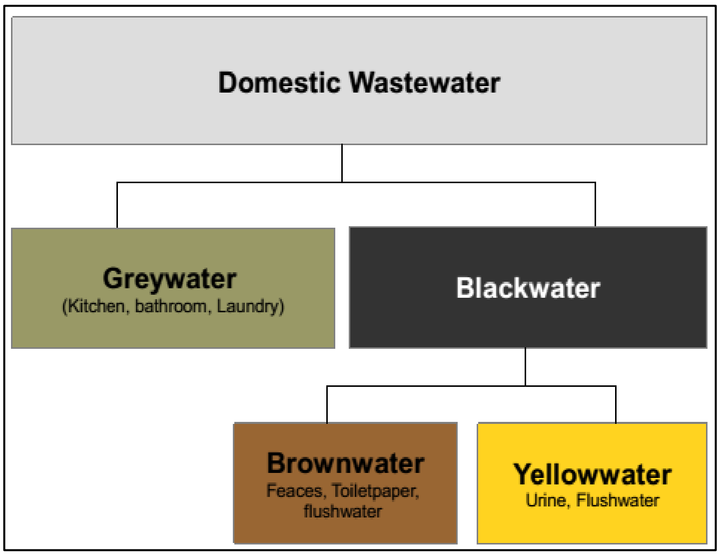


Figure 9: Domestic wastewater and its separate streams (ACF, 2014).

Greywater is defined as wastewater from baths, showers, laundry and kitchen. It excludes wastewater from the toilet (yellowwater and brownwater) (see Figure 9). With a contribution of 50-80% (Li, 2009) in countries with piped water distribution and up to 100% (Morel, 2006) in areas with dry latrines, greywater contributes the largest volume of all three streams to domestic wastewater. However, there is a big variety of the quantity of production and 90-120 l/p/d are typical volumes for countries with advanced water systems (Li, 2009). In countries with low income and water shortages they can be much lower and range between 20-30 l/p/d (Morel, 2006). Mongolian greywater production in the ger districts can even be as low as 6 l/p/d (USTB, 2010). Especially in low income areas the daily amount of GW and its constitution varies significantly, due to its dependency on household activities and type of available water supply (also see Chapter 4.4). On days where e.g. laundry is done, the GW production exceeds daily averages while the pollution decreases. If wastewater from the kitchen contributes as the biggest daily fraction, production values go down while the concentration increases (also see Table 1). Figure 10 demonstrates the heavy daily fluctuations of greywater concentration on the basis of two selected parameters (COD & TSS). Ten samples from the ger area on different days were analysed. Eight samples were taken weekly in summer 2013 and two samples were tested at the USTB in 2010. The USTB data represent minimum and maximum values from 6 tests during that year. The COD ranges heavily from 386-12,144 mg/l and TSS values are between 64-3,200 mg/l. More detailed information about these parameters is presented in Chapter 4.3.1 and a comparison of the values with other countries is discussed in Chapter 4.4.

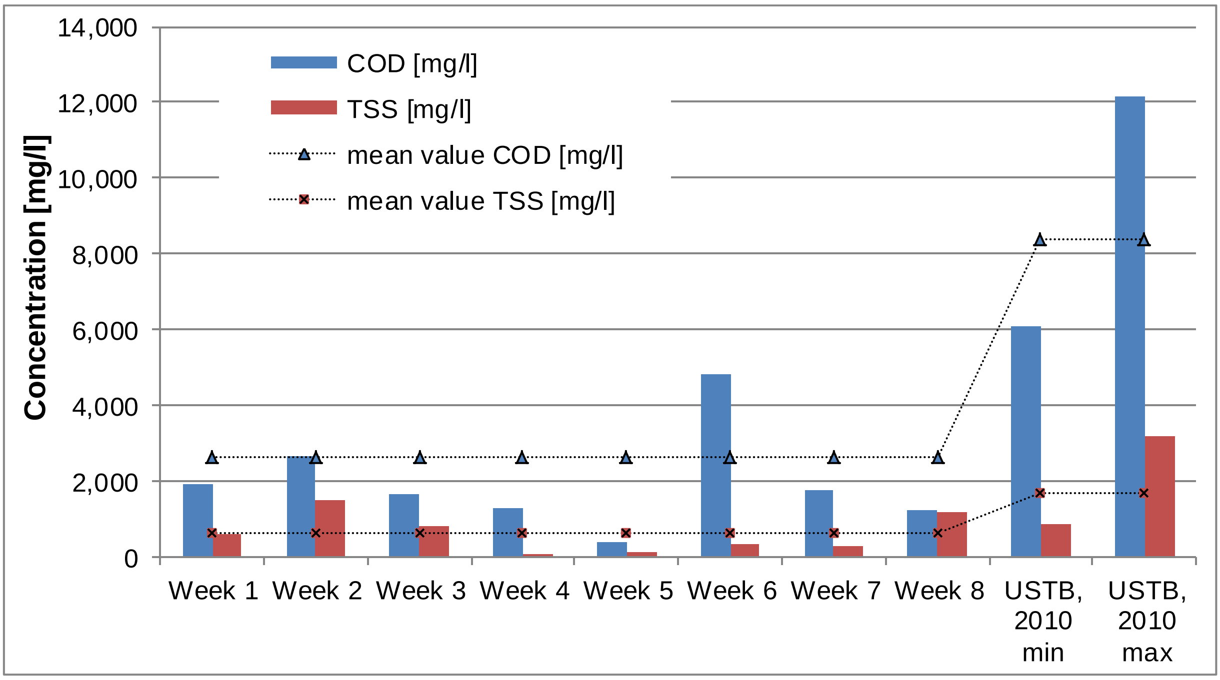


Figure 10: The dependency of GW characteristics on daily activities demonstrated in the fluctuations of COD and TSS concentration, from weekly samples in the ger area (own data, 2013; USTB, 2010) (ACF, 2014).

Since GW is inconstant in both quantity and quality it is important to identify the local characteristics to adapt treatment technologies accordingly. Greywater consists of different sources and the separate streams need to be distinguished due to their specific contribution of pollutants. Table 1 provides an overview of the different sources of greywater and their typical substances and contribution to the entire stream. As general approach it can be stated that effluents from kitchen contribute the highest pollution and bathroom wastewater is the least contaminated of the three sources. The different pollutants implied in the table and their relations to the source are explained in the following chapter.

Table 1: Different greywater sources with selected characteristics and contributions (ACF, 2014).

Source	Contains	Contributes	Remarks
Kitchen	• Food residues • FOGs • detergent • drain cleaner (potentially)	• Nutrients • Suspended Solids • high salt concentration • Organic Substances • Turbidity	• [1]Highest values in BOD, TSS, TN, Total Coliforms • Good Biodegradability
Bathroom	• Soaps • Shampoo • Toothpaste • Skin, Hair • Body Fats • Traces of Urine and Faeces	• Suspended Solids • FOGs • Pathogenic Microorganisms (potentially)	• Deficient in nitrogen & phosphorous • Least contaminated source
Laundry	• High amounts of chemicals; bleaches, solvents • Fibres	• Nitrogen, Phosphorous • Suspended Solids • inorganic particles • Turbidity	• Low contaminated with Microorganisms

[1](Li, 2009)

4.3 Pollutants in Greywater

Greywater contains a big variety of substances that have different effects on the environment and humans. Some important properties of wastewater are not directly pollutants but parameters to determine the quality of the water. The contaminants that are relevant for this study are presented below. In this paper they are subdivided into four major groups, physical characteristics, chemical characteristics, microbial characteristics and FOGs (fat, oil and grease).

4.3.1 Physical Characteristics

Total Suspended Solids (TSS) is the amount of insoluble particles in greywater originating e.g. from food disposals (kitchen), hair (bathroom) or fibres from laundry. High concentrations of TSS can lead to clogging of pipes of the treatment system. Especially inorganic matter from laundry fibres, which is not biodegradable, is one major reason for physical plugging of pipe fittings. Highest content of TSS is supplied by kitchen outflow and laundry (Morel, 2006). The concentration is strongly related to the amount of water used in the specific progress. Lower amounts of water in the progress lead to lower dilution and consequently higher concentrations. The unit of TSS is [mg/l], values found in literature range broadly from 25-183 mg/l (Li, 2009), 50-300mg/l (Morel, 2006). In specific cases, such as the ger districts, they can reach up to 1,500 mg/l (own data, 2013) or even up to 3,200 mg/l (USTB, 2010).

Turbidity is a measure of relative clarity of the water. The higher the amount of suspended particles in the liquid, the lower the amount of light that penetrates through the water because it is scattered by the material. Its unit is NTU (nephelometric turbidity units). On site it is a helpful indicator to provide first visual information about the quality of the water.

4.3.2 Chemical Characteristics

The **Biological Oxygen Demand (BOD)** is a standardised method to measure the organic pollution in wastewater. The test is based on the activity of aerobic microorganisms that metabolise dissolved oxygen under specific conditions. BOD_5 is a standard value that describes the oxidation of bacteria at 20°C over 5 days. A high consumption of oxygen under the given conditions indicates high organic pollution of the water sample. The unit of BOD_5 is commonly expressed in mg O_2 l^{-1}. Observed concentrations in greywater range broadly in different countries, values are documented to range from 120-2,300 mg/l (Morel, 2006) but can be as high as 3,000 mg/l in individual cases (USTB, 2010).

Unlike the BOD, that is limited to biodegradable compounds, the **Chemical Oxygen Demand (COD)** describes the amount of O_2 needed to chemically oxidise all organic material in the greywater. In a laboratory analysis, potassium dichromate is commonly used as strong chemical oxidant. Compared to BOD, the tests for COD are inexpensive and quick. The unit of COD is mg/l and indicates the amount of oxygen used per litre. COD concentrations vary greatly but reach up to 12,144 mg/l as analysed in the ger area (USTB, 2010).

COD/BOD_5 ratio is a valuable parameter that indicates the level of biodegradability of greywater. A low ratio of less than 2 implies high biodegradability, the ratio in greywater is around 0.5 (Morel, 2006; Knerr, 2008). Referring to this value there is a higher potential for a biological treatment of greywater.

There are various **nutrients** in the greywater, those with most significant relevance are **nitrogen (N) and phosphorous (P).** These chemical elements and their diverse appearances are important for animal and plants growth, but in high concentrations they can have negative influence on aquatic life, human health and the microbial population in the soil (Gross, 2005). Nitrogen and Phosphorous occur in different forms in the greywater, some relevant of them are listed below:

- Inorganic nutrients: Ammonia (NH_3), Ammonium (NH_4^+), Nitrate (NO_3^-), Nitrite (NO_2^-), Phosphate (PO_4^{3-})
- Organically bonded nutrient: Particulate N and P (e.g. faecal material, food particles)

The single occurrences can be summed up to Total Nitrogen (TN) for all nitrogen forms and Total Phosphorous (TP) for all phosphorous forms. In comparison to blackwater, greywater tends to provide lower levels of nutrients, since most of them are provided by faeces and urine (Morel, 2006). An important role with regard to biodegradation has the nutrient balance, that can be expressed through the **COD:N:P ratio**. A suggested ration for sewage wastewater is 100:20:1 (Metcalf and Eddy, 1991), mixed greywater values may contain N and P deficiencies though (Jefferson, 2004). Due to its high organic content, wastewater from the kitchen contributes the biggest part of nitrogen to the greywater. Standard values of N in mixed greywater range between 5-50 mg/l (Morel, 2006).

4.3.3 Microbial Characteristics

Apart from physical and chemical pollutants, greywater can be contaminated with pathogenic microorganisms (MOs). Posing a direct health risk, the role of microbiological contamination is particularly significant, if greywater is intended to be recycled for both, potable and non-potable reuse. The concentration of pathogens in comparison to other domestic wastewater sources is commonly perceived to be low, since the highest content is provided by blackwater (Birks, 2006). However, in greywater they can still be present in partly high amounts, originating from e.g. hand washing after using the toilet, or washing babies and diapers after defecation (Friedler, 2004; Gross, 2006; Morel, 2006). Greywater can contain a very broad range of microorganisms, such as viruses, human bacteria or intestinal parasites. To measure the amount of pathogenic pollution, indicator organisms, such as E.coli (*Escherichia coli)* or other faecal coliforms are used. The unit of E.coli is CFU/100ml which is the number of colony forming units found in a 100ml sample.

4.3.4 FOGs (Fat, Oil and Grease)

Since greywater is fed by wastewaters from kitchen sinks and dishwashers, it can contain relevant quantities of FOGs. They originate from several sources such as vegetable oil, cooking fat or meat grease. Problems evolving from significant amounts of FOGs in greywater are significantly given for the treatment systems. As greywater loses temperature when being discharged, containing FOGs cool down and form a more congeal structure. Results may be floating grease layers on top of septic tanks or grease trap and potential clogging of piping systems. As with other pollutants, FOGs concentration in Mongolian greywater is high in comparison to other countries. The reasons for that and more detailed comparisons will be discussed in the following chapter.

4.4 Comparison of Greywater from the Ger Area with other Countries

Both, the composition and the quantity of greywater depend on various factors which can be narrowed down to two main points:

- **Water supply / infrastructure –** Rudimentary water supply (community well, water kiosk, etc.) or advanced piping distribution system
- **Household activities** - Cooking habits, cultural customs influencing the water quantity used, potential re-use of water for e.g. wiping the floor, type of chemicals used for cleaning, household age distribution, etc.

As a consequence the composition of greywater can vary significantly, not only geographically, but also daily, within the same household. Some specific numbers, of different parameters of pollution, between the ger area and other countries are presented in Table 2.

Table 2: Comparison of various greywater characteristics between the Mongolian ger area and other countries (ACF, 2014).

	[1]Nepal	[1]Malaysia	[1]Jordan	[1]Israel	[1]South Africa	[2]Mongolia ger area	[3]Mongolia ger area
Q (l/p/d)	72	≈ 225	≈ 30	≈ 100	≈ 20	≈ 6	≈ 6
pH	n.a.	n.a.	6.7-8.4	6.5-8.2	n.a.	n.a.	5.2-6.4
COD (mg/l)	411	212	n.a.	822	n.a.	1,972	8,366
TSS (mg/l)	98	76	316	330	n.a.	618	1,683
PO_4 (mg/l)	3.1	n.a.	n.a.	126	n.a.	7.5	39.5
NH_4 (mg/l)	13.3	13	n.a.	1.6	n.a.	130	247
Faecal coliforms (CFU/100ml)	n.a.	n.a.	$1.0*10^7$	$2.5*10^6$	n.a.	$5.8*10^5$	n.a.
Water source	In-house taps	In-house taps	In-house taps	In-house taps	Community Well	Water Kiosk	Water Kiosk

[1](Morel, 2006) mean values from specific cases; [2](own data, 2013) mean values from 8 weekly samples at one ger area compound in 2013; [3](USTB, 2010) mean values from 6 different GW samples in the ger area in 2010

n.a. = not available

All international data in Table 2 reflect mean values from specific cases. The first Mongolian data represent mean values of a laboratory analysis from eight samples taken weekly in one ger household in summer 2013. The laboratory tests are performed by the 'Environmental Metric Central Laboratory' in Ulaanbaatar, the application of ISO standards is not confirmed. The USTB data (second Mongolian data) indicate mean values from six different GW samples in the ger area from 2010. The samples are analysed under ISO standards at the USTB laboratory.

The exceeding values of Mongolian GW in most categories demonstrate its special characteristics. Both ger district data significantly top the other countries' mean values with all parameters except PO_4 and E.coli. USTB values for COD are more than ten times higher than Israel's, which provides the highest non Mongolian concentration. NH_4 concentration from USTB exceeds Nepal's values by factor 18. Also Mongolian TSS pollution is 5 times higher than the most concentrated international value. In terms of PO_4 the greywater samples from the ger district do not indicate heavier pollution in comparison to the other countries. E.coli pollution is lower than in Jordan but can still be considered intensely concentrated on an absolute scale.

There are a couple of reasons to explain the high concentrations in the target region. **(1)** Ger households are not connected to a piped water system and freshwater is collected manually from water kiosk. As demonstrated in Table 2, places that utilise in-house water taps produce larger quantities of greywater compared to the countries with community access. In the case of the ger district where freshwater consumption lies around 8 l/p*d the greywater production with 6 l/p*d (USTB, 2010) is extremely low. **(2)** To increase the water use efficiency, it is used repeatedly for different purposes. Greywater from kitchen is fed for watchdogs, discharges from the washing machine are utilised for floor cleaning (USTB, 2010). Instead of being diluted with flush water, as in places with piped distribution, or being dumped after singular usage, it becomes higher contaminated. **(3)** A further major reason is the Mongolian diet. The local kitchen is based on animal products and traditional diet contains a lot of fat and milk.

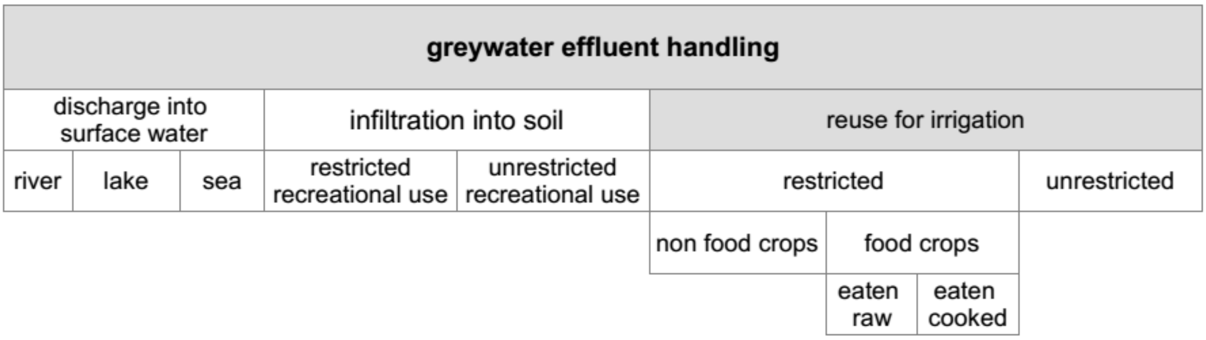
Apart from the geographical discrepancies, greywater from the ger area also indicates great fluctuations on a daily base (see Figure 10). The big differences of minimum and maximum concentrations demonstrate the relation between the pollution and household activities. Mongolian parameters from summer 2013 (own data, 2013) range as follows: COD btween 386-4,824 mg/l, TSS between 64-1,484 mg/l, NH_4 between 1.76-329 mg/l, PO_4 between 4.1-12.3 mg/l and E.coli between $3.7*10^5$- $8.1*10^5$ (CFU/100ml). USTB values from 2010 range as follows: COD between 6,072-12,144 mg/l, TSS between 880-3,200 mg/l, NH_4 between

183.7-322.6 mg/l and PO_4 between 12.6-88.2 mg/l. The fact that the USTB mean values exceed own data in all categories is another indicator that GW pollution is depended on the particular local user pattern. Depending on the purpose of usage of the treated greywater, all pollutants are required to be lower than their specific threshold values to minimize the potential health risks. The type of reuse and according greywater standards applied in this study are presented in the following chapter.

5 Reuse and Discharge Aspects of Greywater

5.1 General Aspects of Greywater Effluent Handling

For a holistic greywater management it is crucial to determine the purpose of usage of the effluent in order to apply appropriate treatment technologies (presented in Chapter 6). Purified greywater can be used for various purposes and depending on the type of application different degrees of purification need to be achieved. The non-potable effluent handling of the greywater in areas without piped water systems can be divided into the following main options:



<table>
<tr><th colspan="9">greywater effluent handling</th></tr>
<tr><td colspan="3">discharge into surface water</td><td colspan="2">infiltration into soil</td><td colspan="4">reuse for irrigation</td></tr>
<tr><td>river</td><td>lake</td><td>sea</td><td>restricted recreational use</td><td>unrestricted recreational use</td><td colspan="3">restricted</td><td>unrestricted</td></tr>
<tr><td colspan="5"></td><td>non food crops</td><td colspan="2">food crops</td><td></td></tr>
<tr><td colspan="6"></td><td>eaten raw</td><td>eaten cooked</td><td></td></tr>
</table>

Figure 11: Important non-potable usage options for greywater effluents in areas without piped water network. Grey boxes indicate the reuse purpose for this study (ACF, 2014).

Some countries have very elaborated guidelines on the usage of greywater effluent for various purposes, while others provide rather general wastewater regulations. Advanced guidelines as provided from the U.S. Environmental Protection Agency (USEPA) imply different standards for handling options and their further subdivisions. They e.g. take into account that surface water discharge implies higher standards on N and P (eutrophication) while nutrients are appreciated in irrigation. In terms of irrigation, unrestricted and restricted reuse can be distinguished, while restricted standards include the type of crop and their processing. Unrestricted irrigation regulations imply that crops are eaten uncooked and respectively standards are stricter (Mara, 2003).

Especially in countries with water scarcity it is favourable to regard greywater as a resource and recycle it accordingly. In Ulaanbaatar’s ger area many residents carry out gardening on their compounds, thus, greywater can be reused for that purpose. The treatment systems in this study aim to achieve effluent quality for reuse for irrigation. Due to the fact that the type of crop in in ger area’s private gardens can vary, unrestricted and restricted irrigation aspects are considered in the context of this research. As greywater regulations are not yet developed in Mongolia different irrigation regulations can be referred to.

5.2 Greywater Regulations for Irrigation

An international wastewater reuse guideline for irrigation is provided by the WHO (WHO, 2006), another relevant reuse regulation is supplied by the USEPA. Both regulations imply high standards that many countries cannot meet due to lacking of financial and human resources (Morel, 2006). As a consequence some countries established independent greywater standards for irrigation that are based on the local feasibility. However, in many low-income states specific GW irrigations regulations are not yet developed and instead rather general wastewater management standards are applied. As this is also the case for Mongolia an abstract of threshold values for restricted and unrestricted irrigation of selected guidelines is presented in Table 3. The EU- bathing water standard is represented due to the fact that it implies whole body immersions and therefore it can be applied as a reference for countries without specific irrigation regulations.

Table 3: Effluent threshold values of different guidelines for restricted & unrestricted irrigation and EU-bathing water (ACF, 2014).

Parameter	[1]WHO	[2]USEPA	[3]Syria	[4]Israel	[4]India	[5]Portugal	[6]EU-bathing water
E.coli [CFU/100ml]	10^3 –10^4 (crops eaten raw) 10^6 (when exposure is limited or regrowth likely)	400	10^5	10	n.a.	100	1,000
TSS [mg/l]	n.a.	30	150	10	200	60	n.a.
COD [mg/l]	n.a.	n.a.	200	100	n.a.	n.a.	n.a.
NH_4 [mg/l]	n.a.	n.a.	5	20	50	n.a.	n.a.
NO_3 [mg/l]	n.a.	n.a.	25	n.a.	n.a.	5	n.a.
NO_2 [mg/l]	n.a.	n.a.	<1	n.a.	n.a.	n.a.	n.a.
TP [mg/l]	n.a.	n.a.	20 (PO_4)	5	n.a.	n.a.	n.a.
Cl^- [mg/l]	n.a.	1	350	n.a.	n.a.	n.a.	n.a.

[1] (WHO, 2006), [2] (Imhof, 2006) for food crops, [3](Mohamed, 2004) for forage, fruit trees & grain, [4](Morel, 2006) for unrestricted irrigation, [5](Matos, 2012) irrigation type not specified , [6](Nolde, 2005)

The application of greywater irrigation standards for this study on the basis of comparison with guidelines from other countries is quite difficult. Simply the fact that elaborated regulations exist in these countries indicates that their reuse sector is further developed than in Mongolia. In addition, greywater constitution and climate conditions vary significantly from those areas where specific standards exist. Even though that threshold values from other guidelines cannot be directly adopted, they provide concentration ranges that can be referred to and they demonstrate the significant differences of effluent requirements. In the context of this study, no specific guideline is being related to. Instead the effluent concentrations from the treatment units from this research are discussed (see Chapter 8.1.3 and 8.2.3) based on the various threshold values provided in Table 3.

To achieve effluent quality that is suitable for irrigation it is important to design treatment systems with multiple purification steps. Ger area greywater that is heavily polluted needs to be pre-treated more intensively, also further treatment steps need to be adjusted accordingly. Treatment steps and mechanisms applied in this research context are explained in the following chapter.

6 Treatment Technologies applied at the Greywater Treatment Units in the Ger Area

6.1 General Aspects

Greywater treatment technologies are a combination of connected treatment technologies to achieve a certain degree of purification of the water. In this study an effluent quality should be achieved to meet the irrigation standards that are determined in Chapter 5.2. The treatment process is divided into several treatment steps, with a graduate improvement of the water quality from one step to the other. In the context of this research two complete Greywater Treatment Units are installed, the Greenhouse Treatment Unit (GHTU) and the Ice Block Unit (IBU). The systems consist of four, respectively three treatment steps – Pre-Treatment, Primary Treatment, Secondary Treatment and Tertiary Treatment – that will be explained in detail below. Apart from the conceptual presentation of the applied technologies design drawings are provided for each step. In combination with the fact that explanations about the process of the construction are also presented, the following chapter can also be regarded as a design manual for the GWTUs.

6.2 Pre-Treatment

As discussed in Chapter 4, greywater characteristics vary strongly and depend on various influences. Therefore there is no universal way of greywater management. In the case of greywater from ger-districts, which is considered highly polluted with e.g. COD and FOGs, an intensified pre-treatment is crucial. To decrease the contamination for the following treatment steps, three different pre-treatment options are installed. A screen and a dual-chamber grease trap at the GHTU and a storage tank at the IBU.

6.2.1 Coarse Filtration - Screen at the Greenhouse Treatment Unit

Greywater can contain considerable amounts of coarse solids in form of e.g. food particles from kitchen or hairs from personal hygiene. The solid matter need to be removed in the beginning of the treatment to prevent clogging of further steps. As indicated in Figure 13, the screen at the GHTU is located at the entrance of the sink. When the system is charged, greywater is poured through the screen. Coarse material is filtered out and can be disposed with the household garbage. The screen is a customized construction that consists of a wooden frame with a mosquito net serving as filter. It is quite common to combine the screen with a grease trap as an option for pre-treatment of greywater (Morel, 2006).

6.2.2 Dual Compartment Grease Trap at the Greenhouse Treatment Unit

Greywater from ger-districts contains high amounts of FOGs which is an important indicator to apply intensive pre-treatment. If FOGs are not removed accordingly in an early stage they can cause plugging of pipes or following filters. For greywater that is highly polluted with FOGs it is prevalent to install a grease trap as a pre-treatment technology. The removal of FOGs with a grease trap is quite efficient and ranges around 70%. For other pollutants, e.g. BOD, TSS, TN, TP, rates are lower than 20% (Morel, 2006). For the GHTU a dual compartment grease trap is installed (Figure 12).

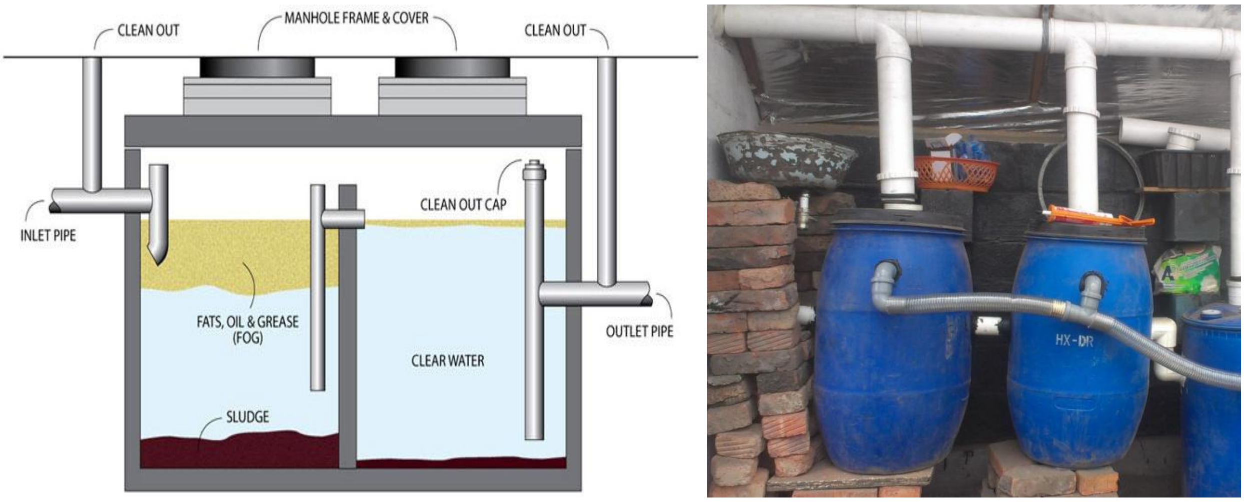


Figure 12: Working mechanism of a dual chamber grease trap (left) & photo of the one constructed at the GHTU (Mahoney Environmental, 2014; ACF, 2013).

The treatment mechanism of the grease trap is fairly simply. Material that is lighter than water floats to the surface and can be removed from there. To achieve a higher purification that process can be repeated in a second chamber. Instead of chambers the grease trap at the GHTU consists of two barrels, the mechanism remains the same. Greywater is transported from one drum to the other from the cleaner middle layer of the water column. Thus, in between the scum layer on the surface and rapidly sunken sediments on the bottom (see Figure 13). In order to avoid that the floating scum layer becomes so thick that it mixes with the effluent it needs to be removed periodically. Since the grease trap at the GHTU is sealed with a lit, a reclosable and air tight 15cm wide manhole is installed on top of the drum (see Figure 13). In addition to allowing access to the surface layer for FOG removal (with a ladle situated on-site), this service point can be used for inspection and maintenance.

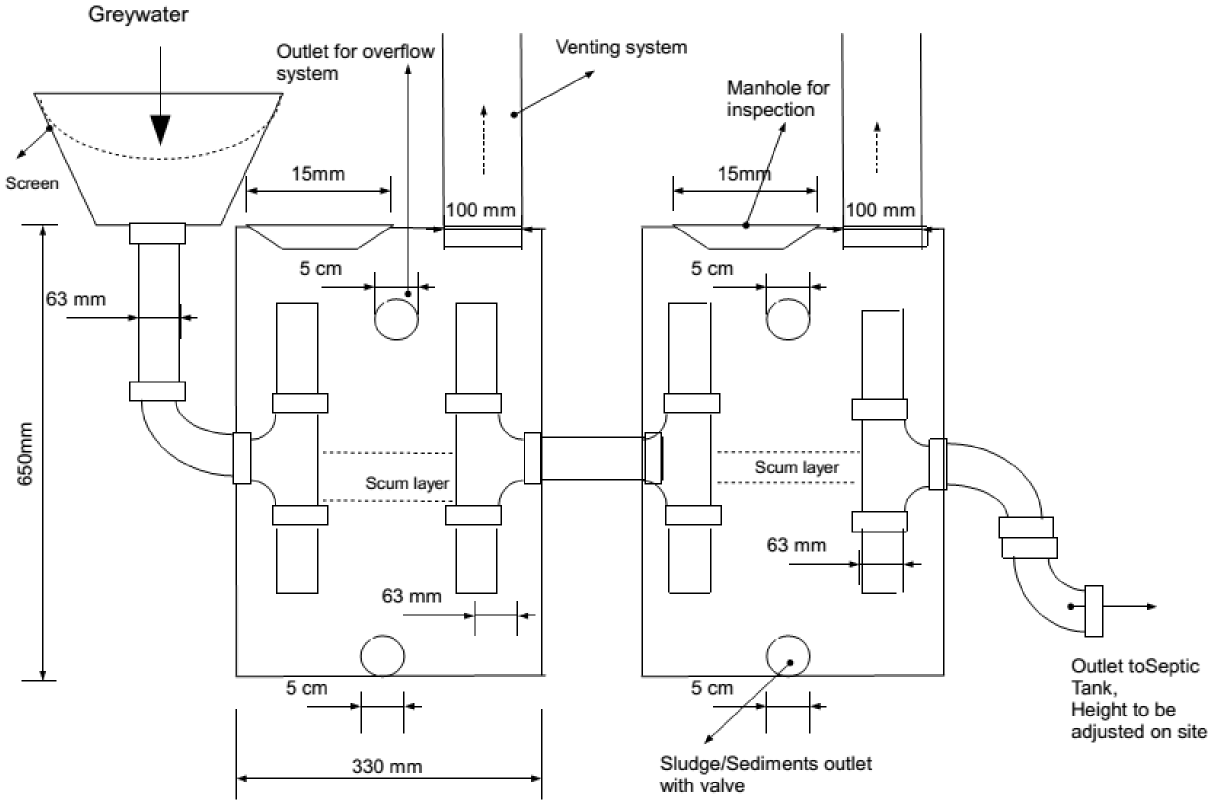


Figure 13: Design drawing of the 'dual compartment' grease trap for the GHTU (ACF, 2013).

The body of the grease trap consists of two plastic drums that originate from Ulaanbaatar’s food industry. In an unmodified state they have a maximum volume capacity of roughly 120 litres each. As the pipe connection between the barrels is located around half height, a volume of about 60 litres per drum (= 120 litres total of grease trap) is given. The total volume is chosen to achieve a hydraulic retention time (HRT) of 2 days at a flow rate of 60 l/d. The basic criteria for the grease trap is to provide enough time for the FOGs to cool down, separate and float to the top layer. Even that minimum HRT requires much lower values than 2 days (>30min, (Morel, 2006)), it has to be assumed that daily greywater production can exceed the average in individual cases. Anyhow, longer HRT are not expected to cause disadvantages, except for bigger amounts of sediments sinking down and accumulating at the bottom. In that case the grease trap works as a septic tank and consequently more frequent desludging is necessary. This can be executed through the sedimentation outlet on the bottom (for detailed maintenance description see Chapter 9.1.2).

Apart from providing enough HRT, it is important to minimise re-suspension of FOGs and solids when the system is charged. At the GHTU, turbulences are decreased because greywater is not applied directly to the scum layer of the grease trap. Instead it enters the first barrel inside the water column via a tee pipe fitting. To prevent air locks, the top ends of the pipes inside the drums are to be left open. The material of the pipes and fittings is polypropylene random copolymer (PPR) which is pricier than Polyvinylchloride (PVC) but provides better quality. The diameters of the pipes is large (63mm outer diameter) to decrease potential of clogging (also see Chapter 8.1.1.1). Further information und summarized facts of the grease trap are provided in Table 4.

Table 4: Summarised information about the dual compartment grease trap at the GHTU (ACF, 2014).

Grease trap	Specification
Working mechanism	Separation of FOGs → floatation Separation of solids → sedimentation
Basic materials applied	Plastic barrels (120l each), PPR pipes (Ø63mm), PPR elbow fittings 90° (Ø63mm), PPR tee fittings (Ø63mm), PPR plug valves (Ø50mm), silicone, hinges, bolt locks, bolts, insulating tape
Technical criteria	HRT: 2 days
[1]Removal rates	FOGs ~ 70%, BOD < 20%, TSS < 20%, TN< 20%, TP < 10%
[2]Max. removal efficiency	COD: 86%, TSS: 86 %, NH_4: 72%, NO_2: 13%, NO_3: 87%, PO_4: 52%, E.coli: 54%
Time for construction	About 2 days with 2 workers
Maintenance	Regular constructional check-ups, pipe cleaning, water level controls, desludging, FOG removal, inner drum cleaning
Advantages	Cost-efficient, robust, simple operation
Challenges	Clogging of pipes through irregular removal of FOGs

[1](Morel, 2006) [2] (own data, 2013)

6.2.3 Storage Pond at the Ice Block Unit

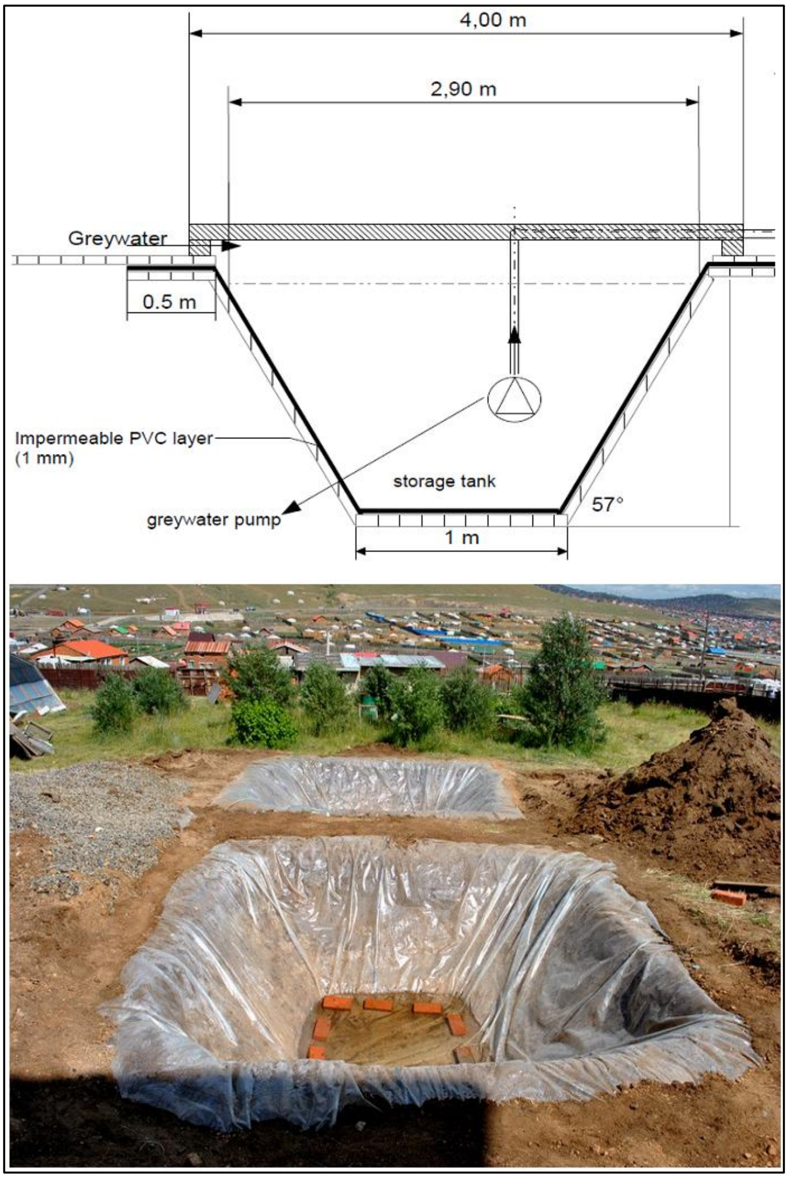


Figure 14: Design drawing of the storage pond at the IBU (top) & Photo during construction (ACF , 2013).

The third type of pre-treatment that is implemented is a storage pond, which is applied at the IBU (see Figure 14). At its original task the pond serves as greywater storage for the winter months when treatment is not possible. Due to the fact that also a first separation of large solids and FOGs takes place inside, it can be considered as a pre-treatment step. The operating mode is as follows: Through the entire year the greywater is pumped from the household to be stored inside the pond. During winter the pond functions as storage where the greywater freezes and becomes an ice block. During summer time, when temperatures are high enough, the water melts down and can be treated. In this time, the greywater is directly transferred from the storage pond to be purified at the further steps.

The storage pond is designed to fit greywater from 3 people producing 8 litres per day each. The estimated per capita production on this particular compound is higher than average in that area. That is based on the fact that a private well is located on-site and therefore there is direct access to groundwater. Storage capacity is designed based on assumptions:

- 7,5 months (middle October-May) with unfeasible water treatment → 225 days
- GW production of 3 people about 24 l/d
- 24 l/d * 225d = 5,400l

With the dimensions of the pond provided in Figure 14 the implemented version has a total volume capacity of about 5,740 litres. The calculations are based on the equation to determine the volume of a truncated pyramid.

$$V = \frac{h}{3} * (G + S + \sqrt{G * S})$$

Where:
G (ground area) = $1m^2$
S (surface area) = $8.4m^2$
h = 1.4m

To protect the storage pond from additional rain fall, a cover consisting of a timber beam frame as substructure and metal plates was constructed. The cover is supplied with a manhole to guarantee access to the pond. The cover raises the costs but brings additional safety. The excavation was undertaken with a dredge which is recommended in terms of time. To fix the PVC membrane a trench (about 20cm wide and 20cm deep) is dug around the pond. The endings of the membrane are laid in there and covered up with gravel and compressed soil. In order to avoid that sharp soil matter causes cracks in the liner, the bottom of the pond is covered with fine sand. Additional information and summarized facts are provided in Table 5.

Table 5: Summarised information about the about the storage pond (with cover) at the IBU (ACF, 2014).

Storage Pond	Specification
Working mechanism	Separation of FOGs → floatation Separation of solids → sedimentation
Basic materials applied	~ 30m^2 PVC membrane (1mm material thickness), timber beams, plastic plates, hinges, bolts
Technical criteria	Storage capacity: 5,740l
[1]Removal rates	COD: 90%, TSS: 80%, PO_4: 64%, E.coli: 70%
[2]Max. removal efficiency	COD: 58%, TSS: 91%, NH_4: 72%, NO_2: 55%, NO_3: 56%, PO_4: 81%, E.coli: 95%
Time for construction	2 days with 2 workers (if excavation carried out by dredge)
Maintenance	Regular constructional check-ups, water level controls (leakages), desludging, FOG removal
Challenges	Emission of odours, living environment for mosquitos, rainwater entering, large surface area required, PVC membrane vulnerable for leakages
Advantages	Simple operation, cheap, good sedimentation properties

[1](CWP, 2007), [2](own data, 2013)

6.3 Primary Treatment

The main objective of primary treatment is the removal of coarse matter, suspended solids that are sedimentable and FOGS that remain in the greywater after pre-treatment. As its mechanisms mainly apply flotation and sedimentation it can be regarded as a physical treatment step. Respectively, colloidal and dissolved particles cannot be removed with this approach. The most common technology of primary treatment in small scale treatment units are septic tanks (Morel, 2006).

6.3.1 Septic Tank

Figure 15: Septic tank at the GHTU during construction (ACF, 2013).

Septic tanks are making use of gravity separation, thus, a combination of sedimentation and flotation. Respectively, the treatment process is similar to the grease trap and based on the same principles. The main difference is that septic tanks are focusing on the sedimentation of particles instead of the flotation of FOGs. As flotation happens faster than the sedimentation of small particles, the volume of the septic tank is designed larger than the volume of the grease trap. Adequate loading capacity needs to be provided, to ensure sufficient time for the particles to settle. Recommended HRTs are >24 hours (Morel, 2006). The septic tanks at the GWTUs are designed with HRTs around 5-6 days to enable the sedimentation of small material and therefore minimise pressure on following treatment steps.

Septic tanks are placed at both GWTUs as technology for primary treatment, a photo of the dual chambered version at the GHTU is presented in Figure 15. The construction type is identical in both units, they only differ in their total loading capacity. The IBU is designed for about 80 l/d, where the GHTU is dimensioned for 60 l/d. The septic tank at the IBU consists of three barrels; the version at the GHTU is built of two drums. The design drawing of the septic tank at the GHTU is provided in Figure 16.

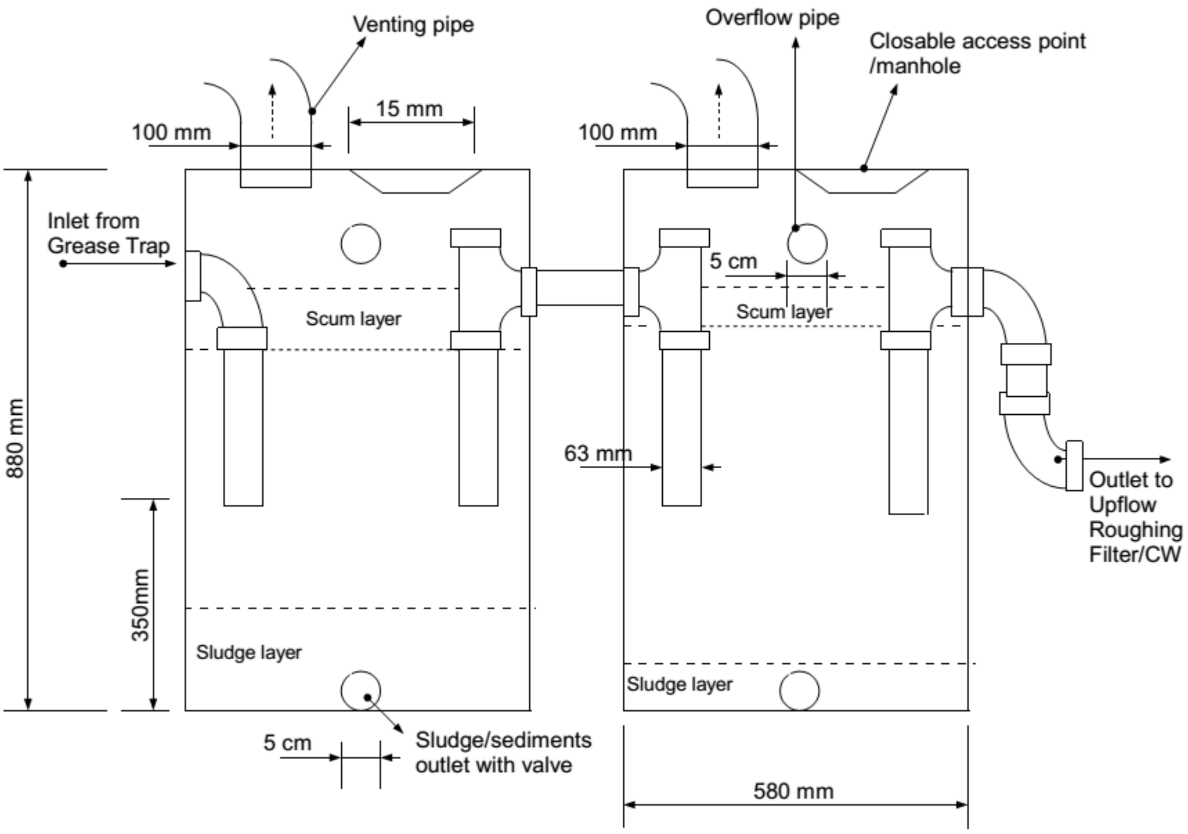


Figure 16: Design drawing of the septic tank for the GHTU (ACF, 2013).

The septic tanks are constructed of standard sized plastic drums that each holds a capacity of roughly 200 litres. Pipe fittings are placed in a height to achieve a loading capacity of about 160 litres for each barrel. This provides 320 litres at the GHTU and 480 litres volume capacity at the IBU. Resulting HRT for the septic tank at GHTU is about 5.4 days and 6 days at the IBU. HRTs above average values are chosen based on the fact that clogging of further treatment steps was identified to be a major challenge of previously installed Units in UB (see Chapter 7). A high HRT increases the purification of small solids that sink slower and therefore risk of plugging is minimised. Apart from the drum sizes, the diameters and materials used are equal to the grease trap. Even the purification is executed the same way, through a transport of the greywater from the cleaner middle layer. The decreasing height of the sludge/scum layer in the drawing indicates the graduate minimisation of sediments/FOGs from one drum to the next. To empty the tanks of the settled sludge a plug valve with Ø 5cm is placed at the bottom of the drum (see Figure 16). By opening the valve the polluted bottom layer of the drum will be released and can be disposed. To prevent clogging of the system this should be done at least once per season. The majority of FOGs is expected to be removed by the grease trap, so the emptying frequency for that is low in comparison to the grease trap. Detailed information on maintenance is provided in Chapter 9.1.3. Additional information and summarized facts about the septic tanks at the GWTUs are presented in Table 6.

Table 6: Summarized facts about the septic tanks at the GWTUs (ACF, 2014).

Septic Tank	Specification
Working mechanism	Physical processes: • Separation of FOGs → floatation, • Separation of solids → sedimentation
Basic materials applied	Plastic barrels (200l each), PPR pipes (Ø63mm), PPR elbow fittings 90° (Ø63mm), PPR tee fittings (Ø63mm), PPR plug valves (Ø50mm), silicone, hinges, bolt locks, bolts, insulating tape
Technical criteria	**GHTU**: HRT: 5.4 days; **IBU:** HRT: 6 days
[1]**Removal rates**	COD: 25-50%, TSS 40-60%, E.coli: 1 [log unit]
[2]**Max. removal efficiency**	COD: 86%, TSS: 86 %, NH_4: 72%, NO_2: 13%, NO_3: 87%, PO_4: 52%, E.coli: 54%
Time for construction	2-3 days with 2 workers
Maintenance	Regular constructional check-ups, pipe cleaning, water level controls, desludging, FOG removal, inner drum cleaning
Challenges	Clogging potential through FOGs
Advantages	Cost-efficient, robust, simple operation, low space requirements

[1](Schüssler, 2010), [2](own data, 2013)

6.4 Secondary Treatment

The secondary treatment follows the primary treatment step and has two main goals: Firstly the removal of organic material (e.g. DOC, slowly settling solids) that remains in the greywater after pre- and primary treatment and secondly the reduction of pathogens and nutrients (Morel, 2006). The treatment in this step is mainly undertaken by biological processes, where pollutants are degraded by microorganisms.

There are two different technologies applied for secondary treatment at the GWTUs. The GHTU is equipped with an upflow roughing filter, where the IBU is provided with a sub-surface constructed wetland. Both technologies are based on the same main principle, which is treatment through media attached biofilms. The filter media in both technologies is differently sized gravel. The gravel serves as surface for microorganisms to grow and perform biological degradation of the pollutants in the greywater. The decomposition process takes place in the aerobic and anaerobic biofilm, where attached MOs mineralise the suspended and dissolved organic substances and metabolise the nutrients. In addition to the biological process, chemical adsorption of pollutants can take place, which reduces chemical constituents such as surfactants. Following, the technologies applied at the GWTUs are presented in detail.

6.4.1 Upflow Roughing Filter (in series) at the Greenhouse Treatment Unit

Upflow roughing filters (UFRF) are fixed bed reactors that are frequently used for secondary treatment of household greywater (Morel, 2006). Its working principle is as follows: As the greywater enters the filter on the bottom, it flows up, comes into contact with the attached biofilm of the media and pollutants are degraded. Upflow direction has the advantage that the accumulated material gradually reduces the pore size in the lower filter bed area, which leads to enhanced pollutants removal towards the top of the filter (interception). In combination with particles sinking down due to gravity (sedimentation) most sludge will be gathered in the bottom area where it can be discharged by plug valves (see Figure 18). The upper part of the filter, where the outlet pipes are located, is loaded less which minimises the risk of plugging. Furthermore UFRF have higher removal efficiencies than horizontal roughing filters (Wegelin, 1996).

Various materials can be used as filter media (e.g. gravel, crushed glass, plastic), it is of significance though to provide a large specific surface area for the microorganisms to grow. Values for good media are 90-300 m^2/m^3 of loaded reactor volume (Sasse, 1998), common material sizes in anaerobic conditions range from 12-55mm (Morel, 2006). UFRF filters usually consist of several stages and it is recommended that the media size decreases successively in direction of the outlet (Wegelin, 1996). The filter media of the roughing filter at the GHTU is gravel (see Figure 17), which is chosen due to good accessibility and affordability in UB.

Figure 17: One compartment out of three of the upflow roughing filter (UFRF) at the GHTU (left) and filter media inside during construction (right) (ACF, 2013).

The UFRF at the GHTU is operated in series and consists of three plastic barrels that each holds a loading capacity of about 160 litres. The complete series respectively has a total volume of roughly 480 litres. The individual compartments contain specific fractions of gravel sizes with the largest fraction (65-50mm) in the beginning and the smallest fraction towards the end of the flow (25-10mm) (see Figure 18).

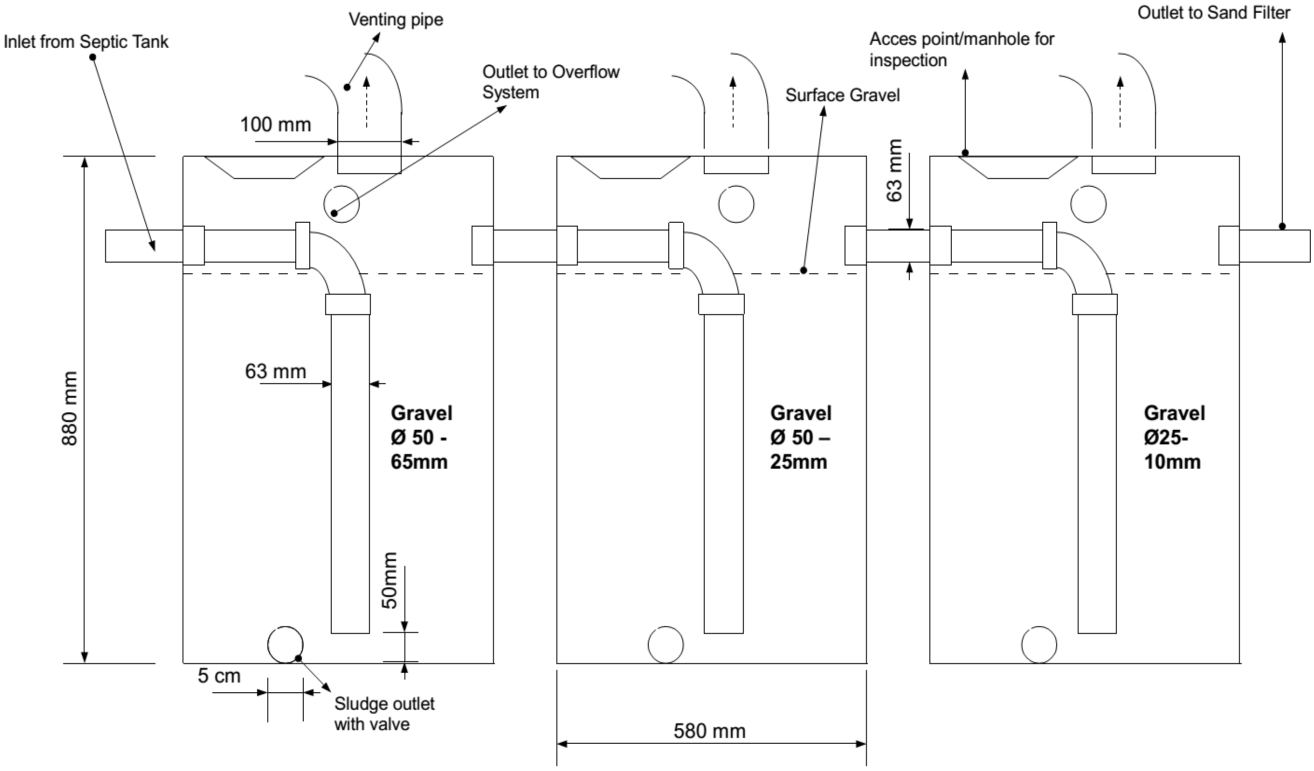


Figure 18: Design drawing of the upflow roughing filter (in series) at the GHTU (ACF, 2013).

The grain sizes are purposely chosen rather high to achieve higher pore volume and therefore to minimise the risk of plugging. Before the barrels were charged with the filter media, the gravel was thoroughly screened and washed. As the UFRF is sealed, an oxygen depleted environment is created and biological degradation happens anaerobically. The decomposition in anaerobic conditions is relatively slow, above that the cold climate limits biological activities. Therefore the filter is designed to provide high HRT of about 8 days. A by-product of the anaerobic digestion is the production of inflammable methane and foul odour, for the evacuation of undesired gases out of the greenhouse a venting system is installed. There is a wind turbine mounted at the end of the of the aeration network to support the discharge. The top gravel layer is covered with a water level of some centimetres. Sufficient distance between the filter media and the outlet pipe ensures that the material will not enter the pipe connection and cause plugging.

Desludging can be carried out through the plug valves installed at the bottom of the barrels. Cleaning of the filter media is required in case the biofilm on the filter media is so thick that it loses its treatment potential. This is recommended to be carried out once per season. More detailed information about the maintenance of the UFGF and detailed guidelines are provided in Chapter 9.1.4. Further information und summarized facts about the upflow roughing filter at the GWTUs are presented in Table 7.

Table 7: Summarized facts about the upflow roughing filter (in series) at the GHTU (ACF, 2014).

UFGF	Specification
Working mechanism	Mainly: Biological degradation through anaerobic digestion Additionally: Physical & chemical processes
Basic materials applied	3 pcs. plastic barrels (200l each), ~ 480l gravel, PPR pipes (Ø63mm), PPR elbow fittings 90° (Ø63mm), PPR plug valves (Ø50mm), silicone, hinges, bolt locks, bolts, insulating tape
Technical criteria	HRT: 8 days, filter depth: ~ 70cm, filter material: three different fractions of gravel (50-65mm, 25-50mm, 10-25mm)
[1]**Removal rates**	Faecal coliforms: 4-5 log reduction, TSS: 99%, Turbidity: 85-90%
[2]**Max removal efficiency**	COD: 93%, TSS: 85%, NH_4: 72%, NO_2: 84%, NO_3: 61%, PO_4: 37%, E.coli: 65%
Time for construction	About 3-4 days with 2 workers
Maintenance	Regular constructional check-ups, pipe cleaning, water level controls, desludging, backwashing, cleaning of filter material
Challenges	Vulnerability to clogging, high time and effort for fractioning and cleaning of gravel during construction
Advantages	Cheap, simple operation, accessible filter material, high removal of COD and TSS, low space requirements, robust

[1](Wegelin, 1996), [2](own data, 2013)

6.4.2 Constructed Wetland - Planted Vertical Flow Subsurface Gravel Filter at the Ice Block Unit

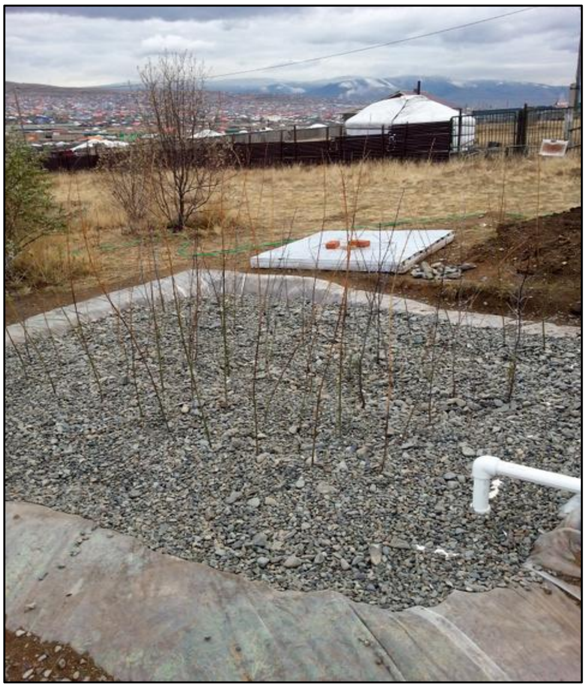


Figure 19: Photo of the VFB constructed wetland planted with willow at the IBU (ACF, 2013).

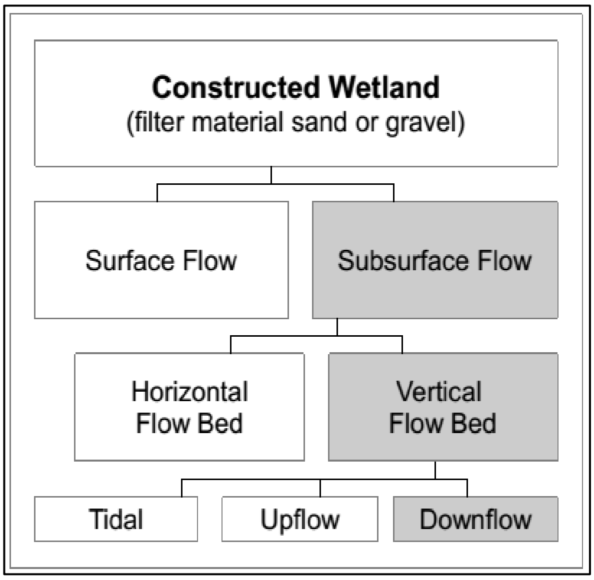


Figure 20: Classification of constructed wetlands. The grey boxes represent the options chosen at the IBU (modified from Hoffmann, 2011).

Constructed wetlands (CWs) are a widely used technology for the decentralised treatment of greywater. The degradation of pollutants is based mainly on biological treatment, even though chemical or physical processes occur as well. The basic treatment mechanism is almost identical to the UFRF which is described above. The main difference is that CWs are provided with aquatic plants. These macrophytes have positive impact on the treatment process in terms of aeration through the root system, nutrient uptake and hydraulic conductivity of the filter bed. Another distinction is that CW work under rather aerobic conditions. Filter media that is typically used in CW is sand or gravel (Hoffmann, 2011). There is a broad variety of feasible construction types, a classification can be undertaken as visualised in Figure 20. The selection of the appropriate option depends on various factors such as area requirements, climate conditions and financial aspects. Based on those, the CW designed for the IBU applies subsurface water level, vertical flow (VF), downflow and gravel as filter media (see Figure 19 and Figure 21). Subsurface flow is chosen based on the fact that it does not contain open water bodies and therefore mosquito breeding and odour production are limited. Vertical flow is applied because area requirements are lower in comparison to horizontal flows (Morel, 2006). The filter media is gravel due to the fact that it implies bigger grain size than sand and consequently the risk of clogging is limited. The design drawing of the vertical flow bed constructed wetland is provided in Figure 21.

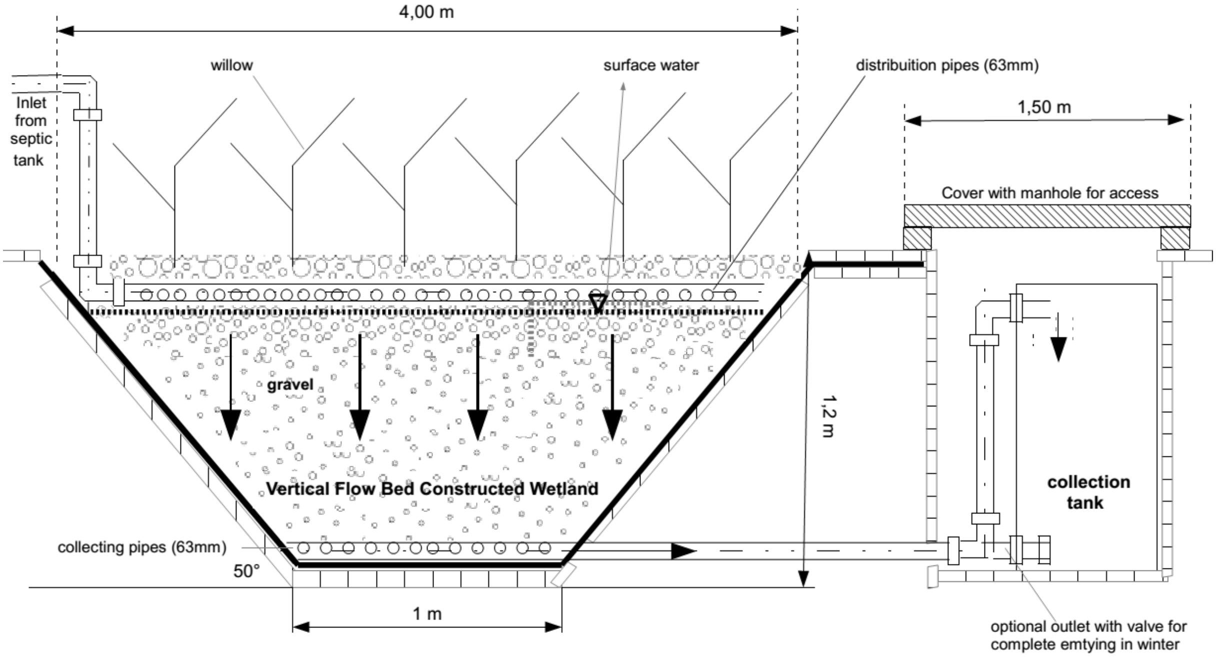


Figure 21: Design drawing of the vertical flow bed constructed wetland and its collecting chamber at the IBU (ACF, 2013).

The depth of the filter bed is about 1m which represents a typical value for vertical flow constructed wetlands (UN-HABITAT, 2008). The surface area of the CW is about 16m^2 and is based on specific area requirements per person for subsurface options. A value of 4m^2/person is recommended for VF types in cold climates (annual average <10°C (Hoffmann, 2011)). 16m^2 is designed based on the approach that 4 people live on the compound through the entire year (3 during the winter months and 5 during summer). The CW wetland is designed for a treatment capacity of 11,000 l/year with a respective flow rate of 78.6 l/d. The values are calculated based on information provided by the user and the following assumptions:

- 3 people live on the compound during winter (7,5 months → 225 days)
- GW Production during that time is 3*8 l/d*225d = 5,400l (see Chapter 6.2.3)
- 5 people live on the compound during summer (4,5 months → 140 days)
- GW Production during that time is 5*8 l/d*140d = 5,600l
- Greywater can only be treated during 140 days per year where T is high enough

The total annual greywater production is 11,000l (5,400l + 5,600l) which needs to be treated during 140 days → Flow rate [l/d] = 11,000l/140d = 78.6 l/d.

Grain size of the filter media is 20-30mm which represents a typical range for submerged wetlands (EPA, 2000; Morel, 2006). The size is achieved through thoroughly screening and sorting out of gravel (see Figure 23). After the fractioning, the gravel is washed in order to eliminate organic particles and other undesired components attached to the media. An impermeable PVC liner is placed at the bottom of the filter bed to prevent water from peculating through the soil. In order to avoid that sharp soil matter causes cracks in the membrane, the ground underneath is covered in fine sand. The macrophytes planted on site are willow and sea buckthorn, which are both commonly used and accessible in UB.

Figure 22: Distribution system with septic tanks (left) and drainage system (right) during construction of the CW at the IBU (ACF, 2013).

As a secondary treatment step the CW is fed with greywater from the septic tank. The distribution of the greywater takes place in a pipe network that is located underneath the top gravel layer. After passing the gravel zone the water is collected with a drainage system on the bottom of the bed (see Figure 22). The pipe networks are built of Ø 63mm PPR pipes and contain holes for an even distribution/collecting of the water. The water level inside the bed is determined by the height of the outlet pipe which is adjusted accordingly to keep the water level subsurface. In addition, the outlet pipe is equipped with a plug valve on the bottom which can be used to empty the system completely for filter media removal. For safety reasons and rain protection the collecting chamber is covered. For better visualisation and understanding of the work process additional pictures are provided in Figure 23. Further information und summarized facts about the CW at the IBU are presented in Table 8.

Figure 23: Screening (top left), loading (bottom left) and cleaning of the gravel during construction & assembling of the distribution system with holes (top right) (ACF, 2013).

Table 8: Summarized facts about the vertical flow bed constructed wetland at the IBU (ACF, 2013).

VFCW	**Specification**
Working mechanism	Mainly: Biological degradation in biofilm Additionally: Chemical adsorption & physical processes
Basic materials applied	~ 40m^2 PVC membrane (1mm material thickness), ~ 7m^3 gravel, PPR pipes (Ø63mm), PPR elbow fittings 90° (Ø63mm), PPR plug valve (Ø63mm), plants (sea buckthorn & willow)
Technical criteria	Type: Subsurface, vertical flow, down flow; filter media: Gravel (20-30mm); HRT: 89 days, filter bed volume : 7m^3 , surface area: 16m^2, HRT: 8 days, filter depth: ~ 1m
Removal rates	^{1}COD: 90%, ^{1}TSS: 90-99%, ^{1}NH$_4$: 90%, ^{2}PO$_4$: 35%, ^{1}E.coli: 3 [log unit]
^{3}Max. removal efficiency	COD: 95%, TSS: 85%, NH$_4$: 96%, NO$_2$: 90%, PO$_4$: 11%, E.coli: 70%
Time for construction	4-5 days with 3 workers (if excavation is carried out by dredge)
Maintenance	Regular check-ups for leakages and water level, cleaning of piping networks, plant harvesting, optional replanting, removal and cleaning of filter media
Challenges	Potential living environment for mosquitos, large surface area required, high time and effort for fractioning and cleaning of gravel during construction
Advantages	Simple operation, accessible filter material, commonly spread, high removal rates

^{1}(Schüssler, 2010), ^{2}(Meulemann, 2003), ^{3}at IBU (own data, 2014)

6.5 Tertiary Treatment

Tertiary treatment step is the last stage of the purification process. It aims at removing those pollutants that still remain in the water after secondary treatment (nutrients, pathogens, etc.) to achieve the desired level of effluent quality. This additional step is only applied at the GHTU which is based on the fact that this system works under anaerobic conditions and is not as effective. A second reason is that removal rates for constructed wetlands are higher especially in terms of pathogens. The technology implemented as tertiary treatment at the GHTU is the slow sand filter which is described in detail in the following.

6.5.1 Slow Sand Filter at the Greenhouse Treatment Unit

Figure 24: The slow sand filter at the GHTU (ACF, 2013).

Slow sand filters (SSF) are commonly combined with UFRF to achieve higher water quality of the effluent (WHO, 2014b). In many cases SSF are used to produce a potable product which is due to their high efficiency in the reduction of pathogens. In the case of the GHTU it is primarily designed to lower the high level of disease transmitting organisms contained in the local greywater and to therefore achieve irrigation quality. Similar to the filter systems at the secondary treatment step, the main process of purification in SSF is conducted by microbiological activities. The sand functions as a substrate for MOs (bacteria, protozoa, rotifera, etc.). They colloid and adsorb onto the sand particles which results in a formation of a dense biofilm in the top layer (see Figure 25). When greywater enters the filter from the top it peculates through the biological active layer where pollutants are trapped in the dense matrix of MOs and become metabolised by its population. The biofilm is referred to as ‘Schmutzdecke’ in the context of SSF and can be some millimetres/centimetres thick.

Depending on various factors (e.g. climate conditions, oxygen supply, organic load) it takes about 10-20 days for the Schmutzdecke to establish, before that time treatment is not effective (EPA, 2014). A photo of the SSF applied at the GHTU is provided in Figure 24, design drawing with technical data is presented in Figure 25.

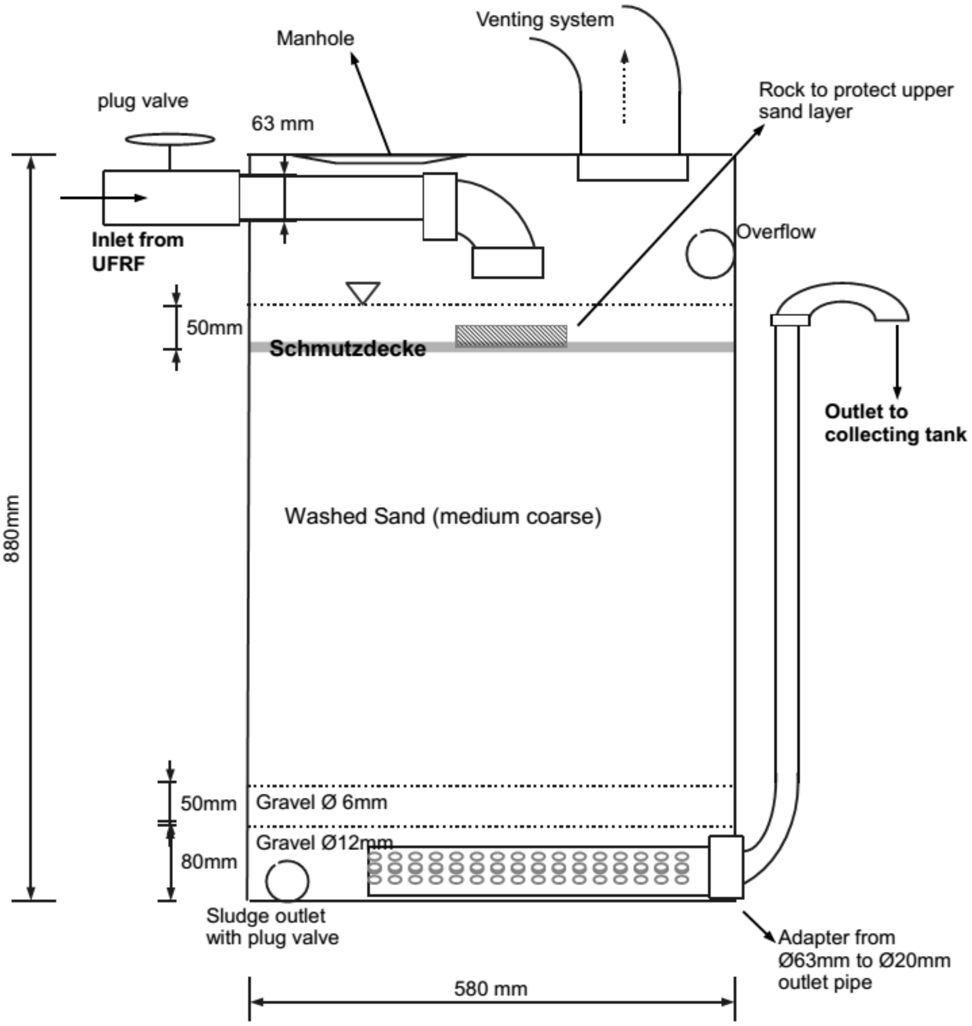


Figure 25: Design drawing of the slow sand filter at the GHTU (ACF, 2013).

The design criteria for the SSF are based on common dimensions for household levels from literature (SUSANA, 2008, Tarsi, 2014). The body of the SSF at the GHTU consists of one plastic barrel with a volume of about 200 litres. The outlet pipe of the filter is mounted in a height that a filter volume of about 170 litres is given. The flow rate is estimated with 60 l/d. The surface area of the filter is about 0.26m^2 and filter depth is about 65cm which is slightly lower than common requirements (WHO, 2014b).

The water column on top of the filter bed is about 5cm high. It is important to maintain the water level covering the top sand layer, because a dried out Schmutzdecke loses its treatment potential (Fewster, 2013). For this reason the outlet pipe is thoroughly adjusted and fixed in a position that ensures the specific water column covering the filter.

Grain sizes and depth of the separating layers are chosen based on recommendations in literature (WHO, 2014b). The perforated drainage pipe at the bottom is covered by an 8cm high gravel layer with grain sizes about 12mm. On top of that is another gravel layer with a height of about 5cm and grain sizes around 6mm. The graduate increase of grain size in the direction of the bottom is designed to prevent clogging of the outlet pipe with sand.

The SSF at the GHTU is supplied with a flat rock (about Ø 10cm) that is placed on top of the media and directly underneath the inlet pipe. It serves as a punctual protection ('splash plate') of the vulnerable Schmutzdecke as it prevents potential destruction of the surface caused by the entering water beam.

The constitution of the sand in SSF is of key importance (due to high vulnerability to clogging), the media should be free of clay (or other fine materials) or organic particles and a specific grain size should be used. Preferably grain sizes should be coarse enough (0.15-0.35mm (Fewster, 2013)) to avoid plugging. Pre-screened or pre-washed sand is not available in UB thus uniform grain sizes are difficult to achieve. For the SSF at the GHTU mainly the sand from the previous unit is used. That sand was already cleaned and prepared (Schüssler, 2010). Before its application at the GHTU, it was washed 3 times to be cleaned and to increase the size. The sand was put into buckets, covered with fresh water and stirred with a wooden bar. While the water was spinning (containing fine sands and pollutants), it was discharged so that coarser and clean sand particles remained. Appropriate grain sizes were determined on the base of visual analysis so exact ranges cannot be provided.

In terms of maintenance the SSF is to be cleaned frequently because a too thick Schmutzdecke reduces the performance of treatment. Hence the top layer (about 0,5-2cm, (DOH, 2003; WHO, 2014b)) is to be scraped off to expose new layers of sand. This should be undertaken once per month and carried out through the provided manhole. The plug valve installed at the inlet pipe provides the possibility to disconnect the SSF from the rest of the unit and allows local adjustments. More detailed information about maintenance and further necessities are presented in Chapter 9.1.5. Further information and summarised facts about the SSF are presented in Table 9.

Table 9: Summarized facts about the slow sand filter at the GHTU (ACF, 2013).

SSF	Specification
Working mechanism	Mainly: Biological degradation in biofilm Additionally: Chemical adsorption, physical processes
Basic materials applied	1 pc. plastic barrel (200l), ~170l sand, ~20l gravel grain size 6mm, ~20l gravel grain size 12mm, PPR pipes (Ø63mm), PPR elbow fittings 90° (Ø63mm), PPR plug valve (Ø63mm), PPR plug valve (Ø50mm), PPR adapter from Ø63mm to Ø20mm, bendable PVC pipe (Ø20mm), silicone, hinges, bolt locks, bolts, insulating tape, flat rock (~Ø10mm)
Technical criteria	Surface area: $0.26 m^2$, filter depth: 65cm, filter volume: ~170l, filter media: washed middle coarse sand, height of water column covering filter bed: ~5cm
Removal rates	[1]COD: 60%, [2]TN: 59%, [3]E.coli.: 99%
[4]Max. removal efficiency	COD: 79%; TSS: 88%, NH_4: 95%, NO_3: 73%; NO_2: 98%, PO_4: 97%; E.coli: 97%
Time for construction	3-4 days with 2 workers
Maintenance	Regular check-ups for leakages, controlling of 5cm water column on top of filter media, water level, cleaning of piping networks, removal of Schmutzdecke, removal and cleaning of filter media, re-sand the filter
Challenges	Vulnerability to clogging; achieving appropriate grain sizes through washing, high time and effort for fractioning and cleaning of the sand during construction
Advantages	Cheap, simple operation, accessible filter material, commonly spread, high removal efficiencies for physical and biological pollutants, low space demand

[1](Schüssler), [2](Li, 2010) , [3](Fewster, 2013), [4](own data, 2013)

The technologies applied in the GWTUs are designed under consideration of previously installed units in the ger area that were malfunctioning. An analysis of their technical shortcomings was undertaken in winter 2012. The summarized results, that provide the base for the particular designs in this paper, are presented in the following chapter.

7 Greywater Treatment Units from 2010 – Description and Evaluation

7.1 General Aspects

In the context of this research topic decentralised greywater treatment systems have been already tested in 2010. Two Greywater Treatment Units (GWTUs) were planned, designed and constructed during that year, the Underground Treatment Unit (UGTU) and a first version of the Greenhouse Treatment Unit (GHTU), the Inside Greenhouse Unit (IGHU). In winter 2012 a field visit was undertaken and it has been found that both systems were not functioning anymore. Based on interviews with the users and on-site observations an identification of their technological shortcomings was established in form of a report. A summarised description of these systems and their evaluation is presented in the following.

7.2 The Underground Treatment Unit from 2010

The UGTU is designed based on the idea that it is located in a chamber underneath the ger/household which is warm enough to prevent the treatment system from freezing during winter. The temperatures above 0°C inside the chamber provide the possibility to perform treatment throughout the entire year. By the time of the field visit the system was already dismantled and leftovers were placed outside the household. The user described that the system was functioning for the first 2 months. After that period it was running slower until it finally clogged. The SSF was observed to be the part with most plugging. Furthermore intense odour was reported. Figure 26 provides an overlook about the inside location, the set up and the flow chart of the system.

Apart from the detected constructional shortcomings (non-functioning grease trap, too small pipe diameter, no overflow system, not properly sealed, no venting system, no sludge recovery, etc.) two major conceptual disadvantages were identified. **(1)** Limited space: It is expected that pilot systems need intense maintenance and numerous technical adjustments which are difficult to carry out in the narrow chamber. In addition up-scaling potential is poor. **(2)** Smell/odour: The production of odour inside the household has negative impacts on the wellbeing of the user. As a consequence of the disadvantages the UGTU was found to be an unsuitable approach and a re-installation was not recommended Figure 27.

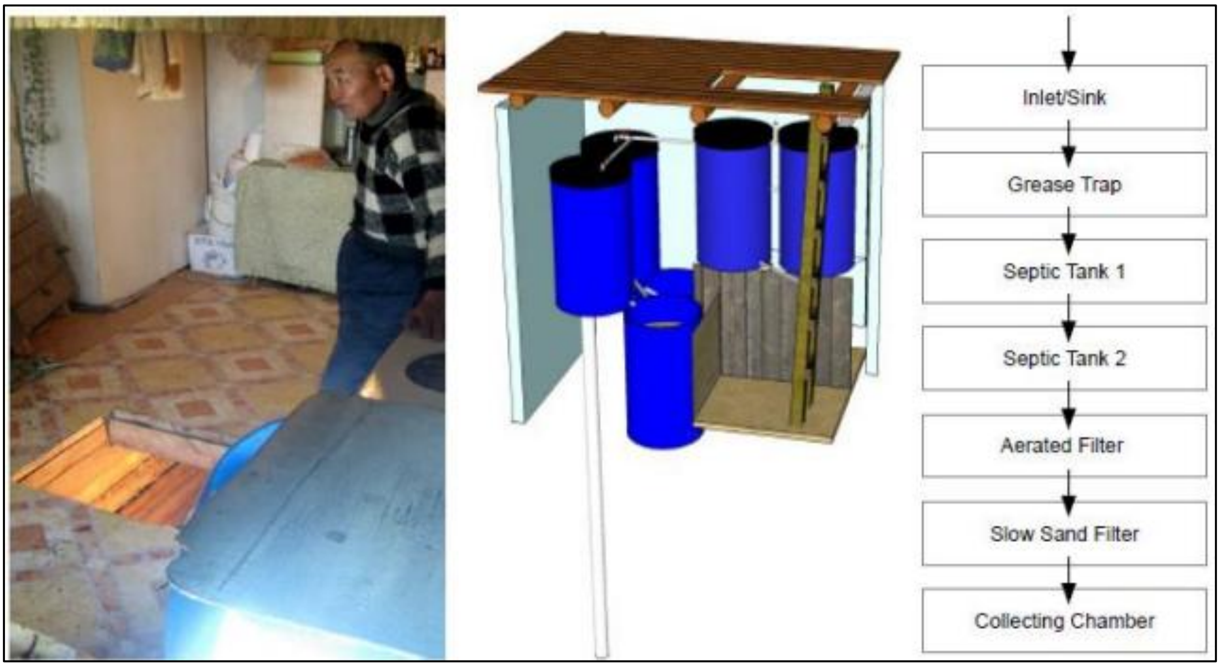


Figure 26: Photo of the location (left), flow chart (right) and model of the UGTU built in 2010 (ACF, 2012; modified by Schüssler, 2010).

7.3 The Inside Greenhouse Unit from 2010

The model of the IGHU serves as an example for the GHTU in this paper and both follow the same approach. The systems are designed based on the idea that higher temperatures inside the greenhouse extend the time period of possible treatment of the greywater. Furthermore the treated effluent can be used for irrigation of plants inside the greenhouse. By the time of the field visit the IGHU was not operating anymore and the system was emptied. The barrels with the containing filter media were still placed in the foreseen arrangement (see Figure 27), what promoted the analysis of technical errors. In addition to observing the constructional set up, interviews were conducted with the user, who reported plugging at the anaerobic filter and the SSF. Moreover the user explained that the system stopped functioning after one month, which resulted in overflowing and intense foul odour.

Based on individual technical analysis and information provided by the user the following technological and structural shortcomings were identified: **(1)** small diameter of the pipes and fittings to and promote plugging, **(2)** system not properly sealed, **(3)** low hydraulic head promotes plugging, **(3)** no venting system to discharge gases and odour, **(4)** no overflow system, **(5)** unsuitable metal barrels that promote corrosion, **(5)** leaking of the pipe fittings, **(6)** system not accordingly sealed, **(7)** too fine grain size in SSF, **(8)** too small grain size in anaerobic filter, **(9)** no maintenance provided, **(10)** no user guidelines provided, **(11)** poor pre-treatment (no grease trap), **(12)** small diameter of the sludge outlet valve promotes plugging.

Figure 27: Photos of the IGHU (built in 2010) with technical shortcomings and flow chart (ACF, 2012; modified by Schüssler, 2010).

Even though the structural implementation demonstrated severe deficiencies the concept was considered to have many advantages. Main benefits are that the temperatures inside the greenhouse provide the possibility to significantly narrow down the cold period and that enough space is provided for adjustments (a more detailed presentation of the benefits are presented in Chapter 8.1). As a consequence the unit was modified, technical adjustments were elaborated and the upgraded designs were recommended for re-installation in summer 2013. Furthermore a new system that was not constructed before (the IBU) was planned and proposed as treatment option with great potential. Table 10 provides summarized information about the evaluation of the GWTUs from 2010.

Table 10: Summarized results from the evaluation in winter 2012 of the GWTUs from 2010 (ACF, 2014).

	Underground Treatment Unit	Inside Greenhouse Unit
Current state	Non-functioning, dismantled	Non-functioning, empty, still on site
Disadvantages	• limited space • odour inside the household • limited up scaling potential • promotes unhygienic conditions inside the household/ger	Whole year treatment not possible
Advantages	Whole year treatment possible	Space, motivated user, greenhouse brings additional benefits
Problem	Clogging & overflow, odour	Clogging & overflow, odour
Identification of technical shortcomings	• inadequate loading • grain size filter • no ventilation system • small diameter • malfunctioning grease trap	• poor pre-treatment (no grease trap) • too small Ø of pipes & fittings • no venting system • inappropriate grain size • metal barrels promote corrosion • low slope (hydraulic head) • no overflow system • wrong dimensioning of SSF • not accordingly sealed (odour, leaking) • no user-/maintenance guidelines provided
Recommendation	Re-construction not recommended ➔ based on major disadvantages	Re-installation recommended ➔ with major technical adjustments ➔ up scaling potential ➔ great overall potential
Action plan	Abandon concept	Re-installation with new design ➔ technical and conceptual improvements early 2013 ➔ implementation in summer 2013

8 Greywater Treatment Units 2013 – Greenhouse Treatment Unit and Ice Block Unit

The GWTUs in this study aim at providing solutions for mitigating the environmental impact resulting from uncontrolled wastewater disposal in Ulaanbaatar's ger area, while lowering water stress by reusing greywater. Based on the evaluation and lesson learnt from the previous units in winter 2012, two GWTUs were developed and constructed during summer 2013. The Greenhouse Treatment Unit (GHTU) and the Ice Block Unit (IBU) are presented in detail below. The new systems are designed under consideration of the following factors and requirements:

Decentralised operation: The systems are designed to provide a decentralised greywater treatment in the ger area with no connection to the central sewage network.

No connection to the central sewage network in the near future: The systems are designed under the assumption that there are no plans of the city's government to extend the water distribution system to the outskirts of the city.

Household level: The units are designed as a small scale approach at household level. The systems are suitable for the people on the compound with no connection to a central water supply system. Low flow rates are considered.

Reuse for irrigation: There are various purposes that treated wastewater can be used for. The GWTUs are designed to achieve irrigation standards, so that the effluent can be used for the vegetation on the compound.

Heavily polluted greywater: The greywater in Mongolia is highly concentrated with COD, FOGs and other pollutants and values are higher in comparison with other low income areas.

Varying daily flows: Daily greywater production is inconstant in the ger district and flow rates can vary significantly. Especially on days when laundry is done the hydraulic loading of the system can exceed the average values.

Extreme temperatures: Temperatures drop below -40°C, freezing soil down to about 3.5m depth from around November-May (6–7 months per year). The biological processes that perform a large part of the purification are negatively influenced by cold temperatures. Most low budget GWTUs that were successfully tested are located in more temperate regions.

Economically affordability: Designs aim to provide low budget solutions for the people in the ger area. Materials are affordable and additional energy supply is minimised to keep expenses low.

Availability of materials: The GWTUs apply material that is locally available and easily accessible.

Potential for up-scaling: The treatment systems in this study are sized for household level, but they are designed under consideration of their potential for up-scaling. If the systems proof to be effective they can be up-scaled to provide treatment solution for a larger area.

Potential for reproduction: The systems are based on simple treatment mechanisms and affordable and available materials. They are designed in a replicable manner so if the system proofs feasibility job opportunities can evolve.

Simple and user-friendly: The units are designed to be operated by the people of the ger/household. Hence the systems aim to provide convenient, robust and understandable options for the user with low need in maintenance, users should be able to conveniently feed and operate the system.

Pilot system approach: It is expected that the units will need frequent technical adjustment in the early phase of the operation. Furthermore it is to consider that biological activities will need some time to start, so efficiency can be low after initiation. In order to see if that type of treatment is possible, high quality materials are used to support performance stability. If the systems prove to be suitable for reproduction, material standards could be downgraded resulting in lower total costs.

8.1 The Greenhouse Treatment Unit

The design of GHTU is based on the IGHU from 2010 and follows the same approach: It extends the annual period when greywater treatment is possible by taking advantage of higher temperatures inside the greenhouse. By limiting the period of wastewater discharge into the ground, the accumulation of pollutants decreases and hygiene standards can be improved. As a benefit of the treatment the clean effluent could be used for the irrigation of plants in the greenhouse or garden and therefore water stress can be reduced. The set-up and the location of the system are presented in Figure 28.

Figure 28: Set up and location of the Greenhouse Treatment Unit (GHTU) (ACF, 2013).

8.1.1 Modifications from the Inside Greenhouse Unit to Greenhouse Treatment Unit

After the IGHU was not operating accordingly and demonstrated severe technological shortcomings (see Chapter 7.3) major modifications were established. The upgraded treatment unit was further developed in two ways; firstly through an application of constructional adjustments ('how was it build') and secondly through a modification of the system ('what technologies were applied'). The improvements made from IGHU to GHTU are visualised in Figure 29 and discussed in the following.

8.1.1.1 Constructional Adjustments from the Inside Greenhouse Unit

Increase of the diameter of pipes and sludge outlets: The GWTUs rely on biological activities which result in the production of sludge. The organic mass naturally sinks down or settles in the pores of the filters. As greywater flows to the next treatment compartment it can contain parts of the sludge which causes plugging if diameters are not designed accordingly. The IGHU was supplied with plastic pipes and iron sludge outlets of Ø 20mm. The pipes and sludge outlets at the GHTU are designed with Ø 63mm PPR pipes and Ø 50mm sludge outlets to lower the risk of plugging.

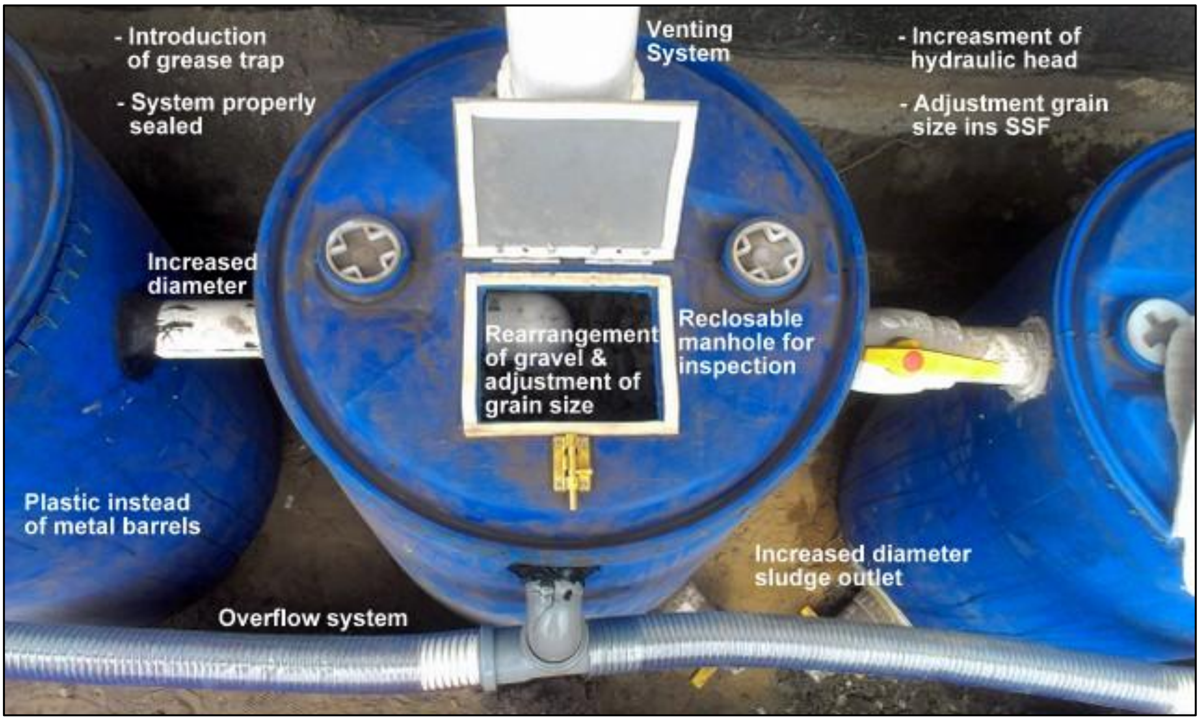


Figure 29: Visualization of the technical adjustments applied at the GHTU (ACF, 2013).

Grain size increase and adjustment of arrangement: The anaerobic filter at the IGHU was arranged as ‘upflow in layers’, which implies that small grain sized gravel was located in the first treatment chamber. With small filter particles in an early treatment chamber the risk of plugging is promoted. The UFRF at the GHTU is arranged as 'upflow in series' and instead of layers that include fine particles, exclusively coarse gravel is placed in the first barrel. That leaves more pores volume for the sludge to settle and risk of plugging is limited. Instead of decreasing the grain sizes vertically in layers, the filter media size is gradually reduced in the direction of the flow (also see Chapter 6.4.1)

Proper sealing of the system: The metal barrels at the IGHU were supplied with lids that were not completely air tight. That resulted in the fact that users complained about strong odours inside the greenhouse. The plastic barrels at the GHTU are provided with air tight lids and silicone was applied to appropriately seal the system.

Installation of manholes: Since the system is completely sealed access points are provided on the lid of each barrel. These manholes are supplied with an air tight and recloseable cover. The access points can be used for adjustments, sampling, maintenance or the removal of sludge/FOGs.

Increase of hydraulic head: To increase the pressure by which greywater is transferred through the pipe systems the slope of the series is heightened. That has the effect that sludge is less likely to remain in the connecting pipes which results in a minimised risk of plugging. This is practically implanted, as the SSF filter is arranged in a lower position while the water level at the inlet (grease trap) is elevated.

Plastic instead of metal barrels: The metal drums at the IGHU proved to be unsuitable because of their vulnerability to corrosion and their inconvenience in tooling and constructing. The GHTU is provided with plastic barrels from the nearby food industry.

Adjustments grain size SSF: The sand in the SSF at the IGHU appeared to be too fine (clogging). At the GHTU the sand is washed several times to achieve coarser size and to be freed from silt and organic particles.

8.1.1.2 System Modifications from the Inside Greenhouse Unit

Improvement of pre-treatment by introduction of a grease trap: Greywater from the ger district is highly contaminated with pollutants, particularly FOGs and COD values are high. The high concentrations of the contaminants indicate that intensive pre-treatment should be performed. The minor developed pre-treatment at the IGHU was identified to be a major reason for the malfunctioning. To lower the pressure on further treatment steps a dual compartment grease trap is installed.

Installation of an overflow system: The GHTU is supplied with an overflow system. Each barrel is connected to the system so if clogging occurs wastewater is evacuated through the hoes system out of the greenhouse.

Introduction of venting a system: Smell and odour were documented to be a major challenge at the previous treatment systems. Due to the fact that the biological processes take place in oxygen depleted environments, foul gases (e.g. H_2S) and methane are produced. Methane causes dangers because it is an inflammable gas, while intense odour is extremely unpleasant for the user. In addition H_2S is toxic. Therefore a venting system is designed which is connected to a wind turbine outside the greenhouse to promote the discharge (see Figure 28). The system consists of a 10cm diameter PVC pipe network, which is connected to each barrel through the lid and is applied air tightly with silicone. A visualisation of the differences between the IGHU and the GHTU is presented in Figure 30.

Figure 30: Visualization of the difference between the IGHU from 2010 (left) and the GHTU from 2013 (right) (ACF, 2013).

8.1.2 Setup and Operation of the Greenhouse Treatment Unit

The **setup** of the GHTU consists of four treatment steps, a visualisation of the system is provided in Figure 31. The **pre-treatment** is carried out by the mosquito net screen and the dual chamber grease trap. Coarse solids will remain in the screen and can be disposed with the household garbage. The grease trap separates rapidly sinking particles and floating FOGs from the greywater. For **primary treatment** two septic tank compartments are provided. The HRT of the GW is longer in this stage, consequently solids that sink slower are provided with more time to settle at the bottom. The **secondary treatment** step consists of three upflow roughing filters (in series) that mainly perform biological treatment. The filter media is gravel in different sizes (decreasing in size in the direction of flow) which serves as surface area for microorganisms to develop. **Tertiary treatment** is carried out by the slow sand filter where remaining dissolved organics and pathogens are degraded in the Schmutzdecke layer (for detailed explanation of the treatment steps see Chapter 6). The **treated effluent** is collected in a plastic drum at the end of the treatment series. Each barrel of the system is connected to the overflow system, so in case of plugging the greywater will be evacuated outside of the greenhouse. To discharge undesired gases (e.g. inflammable methane or H_2S) and odours that result from the anaerobic processes a venting system is installed. This piping network is connected to each barrel and provided with a wind turbine outside the greenhouse that supports the discharge.

The operation of the GHTU is scheduled to run for about 8 months per year (mid-March – mid-November). Temperatures inside the greenhouse in November 2012 were recorded significantly above 0°C (own data, 2013), so it is assumed that treatment can be carried out until that time. During the 4 months when treatment is not possible, the water can be either stored (not foreseen in this study) or disposed in the old fashioned manner. The GHTU is operated primarily by the user. GW is collected in the ger/household and manually fed on a batch basis into the system (through the sink) with e.g. plastic buckets. The water is transported through the system on the base of gravity and pressure (hydrostatic pressure) as described by the 'law of communicating vessels'. It is not required to provide the system with additional energy. The system is designed for a daily flow of 60 litres. Up to 6 people living on the compound with a daily production of about 6 l/p. 60 l/d is purposely chosen higher due to daily production fluctuations (laundry, visitors, etc.).

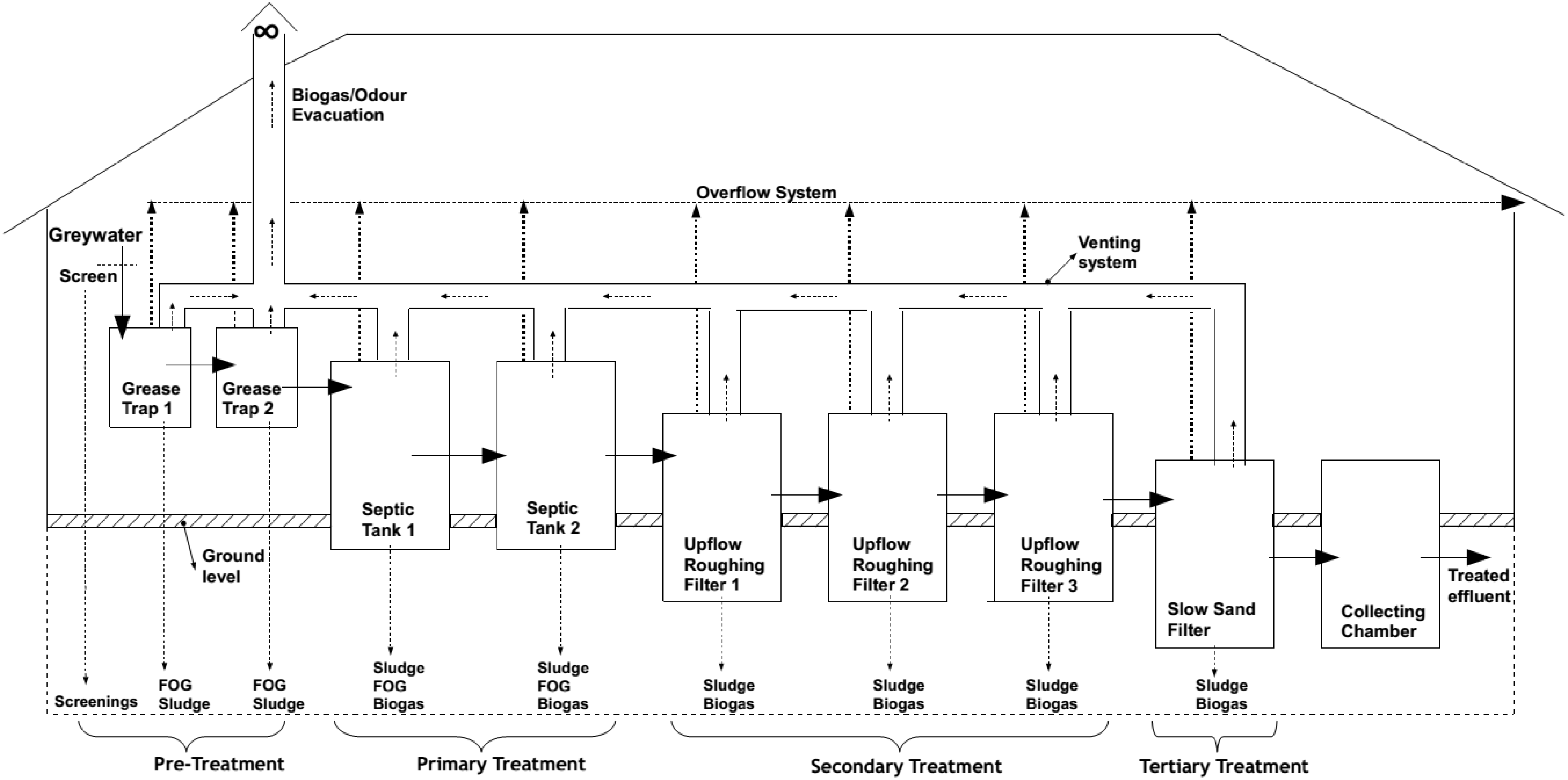


Figure 31: Concept, set-up and flow chart of the GHTU (ACF, 2013).

8.1.3 Performance of the Greenhouse Treatment Unit

Figure 32: Connecting pipe between barrels supplied with a flexible hose for sampling (ACF, 2013).

Based on removal rates from literature, calculations about the treatment efficiency were already performed for the previous unit (IGHU from 2010) and its potential to provide adequate purification was demonstrated in theory (see Schüssler, 2010). After the new installation of the GHTU was completed in 2013, a series of eight water quality tests were carried out. From September until October 2013, weekly samples were taken at the GHTU. In addition to weekly quality tests for influent and effluent, samples were also analysed after each treatment step (see Chapter 6 for removal rates of the treatment technologies applied). The samples in between the different technologies were taken through an attached flexible hose. The tube can be closed again with a provided small wire (see Figure 32). A chemical analysis was carried out for the pollutants COD, TSS, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, while E.coli was tested as biological parameter. The specific contaminants were chosen as they are common representatives for physical, chemical and biological pollution and therefore enable comparison with parameters from literature. The laboratory analysis was performed by the 'Environmental Metric Central Laboratory' in Ulaanbaatar. The system's performance, in form of influent and effluent values, is presented graphically in the following figures and will be discussed below. Furthermore a visual analysis that was executed shortly after the initiation of the GHTU is presented.

The sampling values need to be considered critically as the following factors can have negative impact on the quality of the data: **(1)** GW influent taken from grease trap barrel so already passed the screen, **(2)** Analysis at metric centre not under ISO standards, **(3)** Transport, **(4)** Time between sampling and analysis, **(5)** Different people involved in sampling process, **(6)** Sampling hose located at the bottom of connecting pipes where sedimentation is favoured.

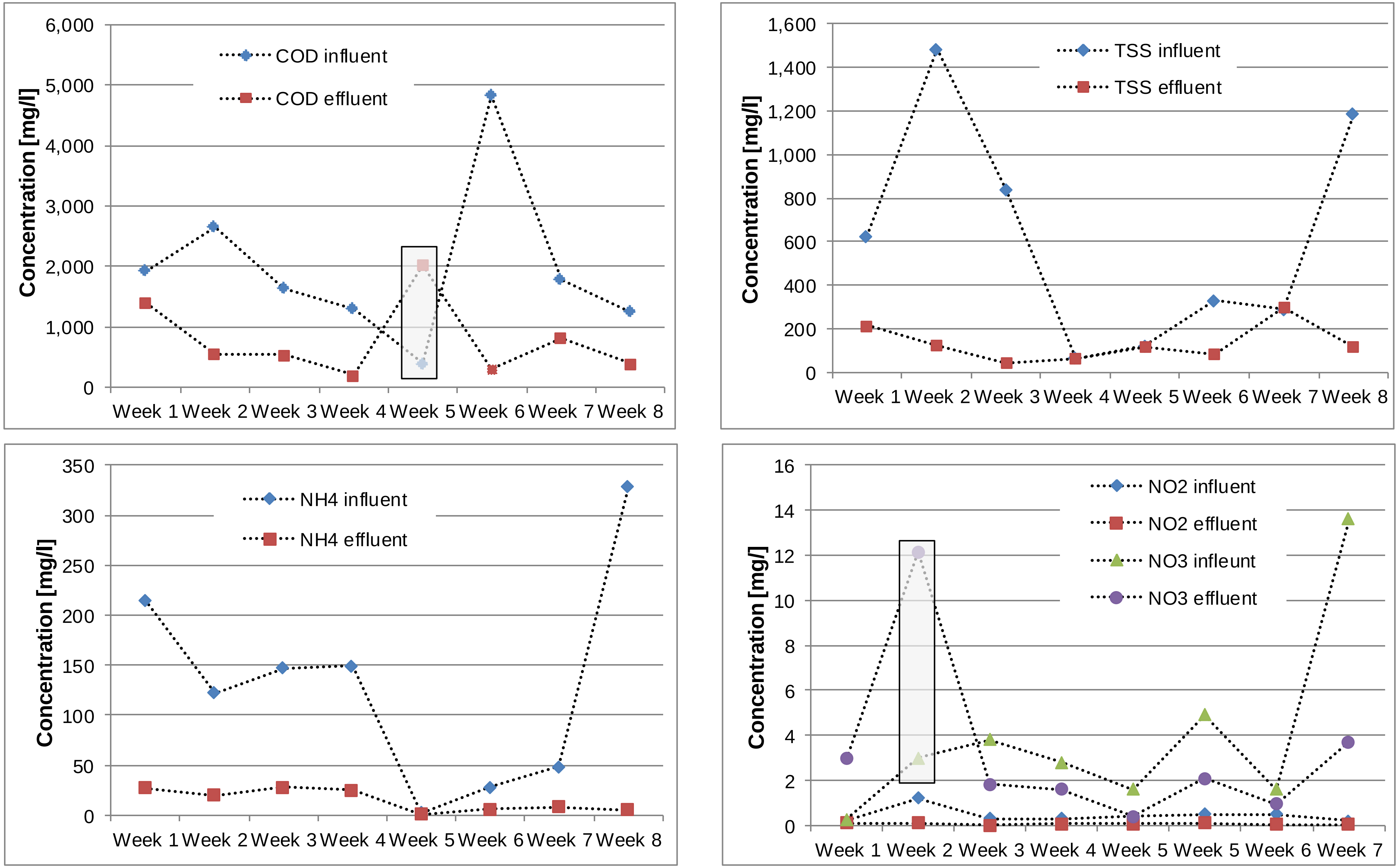


Figure 33: Influent and effluent concentration of COD, TSS, NH_4, NO_3 and NO_2 from an 8 week sampling series in September and October 2013 at the GHTU (ACF, 2014).

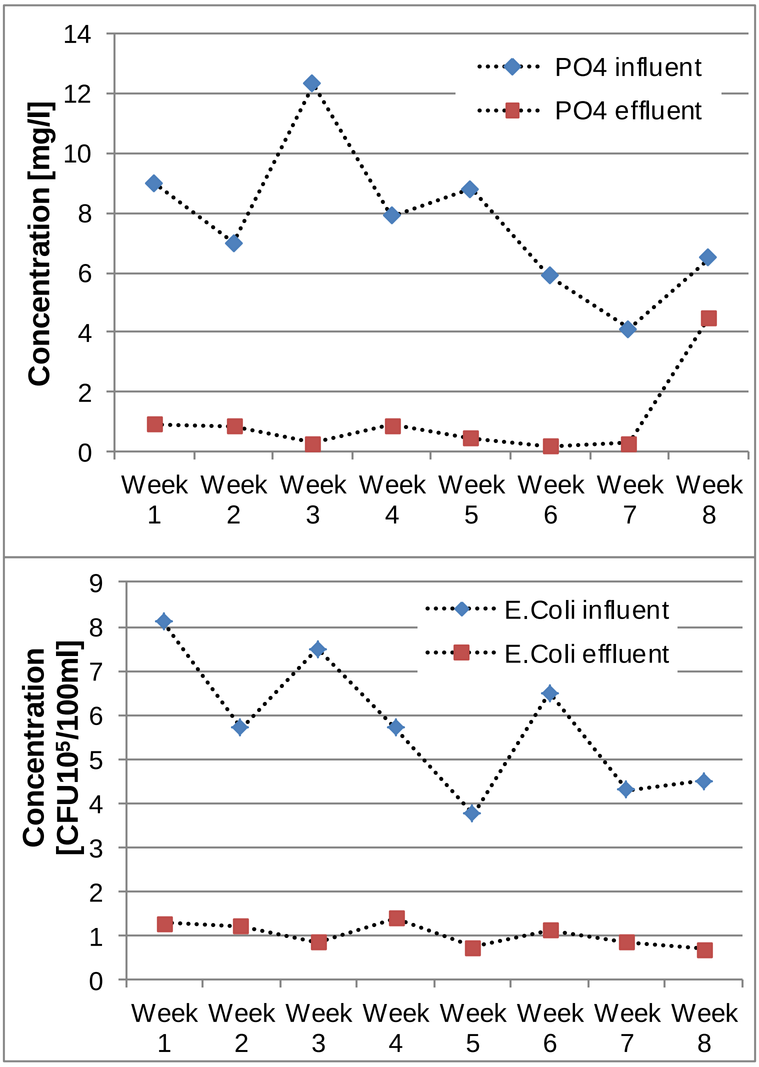


Figure 34: Influent and effluent concentration of PO_4 and E.coli from an 8 week sampling series in September and October 2013 at the GHTU (ACF, 2014).

The COD concentration of the influent varies from 385.9-4,924 mg/l, while the effluent ranges from 139-820 mg/l. The big discrepancies between the effluent values could be explained firstly through the high fluctuation of greywater production, with resulting varying HRT in the treatment steps. And secondly through the major differences of influent concentrations that depend on the daily consumption pattern of the user. The maximum removal rate of COD is reached in week six and accounts to 94%, demonstrating the high removal potential of the GHTU. The abnormalities in week five are assumed to be caused by an exchange of the samples. In addition the method of taking the samples, the transport or laboratory inaccuracies could have led to a falsification of the results. The comparably high effluent value from week one can be explained with the fact that biological activity was not adequately developed in the beginning. The mean effluent value of COD is 596 mg/l (excluding week 5), which exceeds the standards presented in this study.

The concentrations of TSS in the influent range between 66-1,484 mg/l, while the greywater from the outlet ranges from 44 to 290 mg/l. Even though TSS influent concentrations vary greatly the system performs steady levels of reduction. The maximum removal rate for TSS (week 2) is 92%. The mean effluent concentration is 124 mg/l, respectively the guideline from India for unrestricted irrigation is met (see Chapter 5.2).

NH_4 values from influent range from 1.76-328.6 mg/l, whereas the treated samples lie in the range of 0.64-28.2 mg/l. Maximum removal rate of 98% is achieved in week eight. Mean effluent concentration is 15 mg/l which is lower than the guideline from Israel for unrestricted irrigation (see Chapter 5.2).

Influent concentrations for NO_3 range from 0.25-13.6 mg/l, while effluent values lie between 0.4-2.96 mg/l (excluding week 2). With respect to the unusual values in week 2 it is assumed that sampling or analysing failures occurred. The maximum removal rate is 73%. Mean effluent concentration accounts 1.9 mg/l which is below the threshold value irrigation guidelines in Portugal (see Chapter 5.2). Nitrite values of the influent range between 0.16 and 1.13 mg/l, the effluent concentrations vary from 0.04-0.15 mg/l. The fact that NO_2 reduction is low in some weeks could be correlated to an uncompleted denitrification. As anaerobic conditions are present in the system, denitrification occurs which is the two step reaction from NO_2 to N_2. During the first reaction NO_3 is transformed into the intermediate product NO_2, in the second step, NO_2 is converted to N_2. As the entire process is relatively slow and additionally limited due to cold temperatures, it might not have been completed within the HRT of biological treatment steps (UFRF & SSF). Consequently some NO_3 from the influent is simply transformed to NO_2 throughout the treatment. Nonetheless the mean effluent concentration remains low with 0.07 mg/l and meets restricted Syrian irrigation standards (see Chapter 5.2).

In terms of PO_4 removal the GHTU demonstrated high efficiency with maximum removal rates of 98% and effluent concentrations are constantly below 0.924 mg/l (excluding week 8). Respectively regulations for unrestricted irrigation in Israel are met (see Chapter 5.2).

Greywater values from influent vary from 375,000-810,000 CFU/100ml for E.coli, the treated samples range from 71,000-140,000 CFU/100ml. Even with a maximum removal rate of 88.4% the mean effluent concentration with 103,000 CFU/100ml remains high and does not meet standards for unrestricted irrigation. However, WHO standards on restricted irrigation are almost met, as threshold values are 100,000 CFU/100ml if exposure is limited or if regrowth is likely (see Chapter 5.2).

The overall performance of the GHTU provided satisfying results. The fluctuations of the removal efficiencies can be explained with highly varying influent compositions and different daily GW production resulting in irregular hydraulic retention times. However, the maximum removal rates exceed 88% for all separate parameters excluding NO_2. The high removal values could be related to the high hydraulic retention times in the treatment steps that enables also the reduction of slowly biodegradable organics. Furthermore they can be based on the fact that GW concentrations from the ger area exceed the values from other studies, so a relatively high reduction is more likely to be achieved. The high amounts of E.coli remaining in the effluent need to be regarded sceptically. To achieve higher effluent quality, especially in terms of pathogens, a second SSF filter can be added to the GHTU. The maximum removal rate of the SSF is 97% and indicates high efficiency in terms of faecal coliform reduction. On the basis of this value the mean effluent concentration could be decreased to 3,090 CFU/100ml and restricted irrigation standard could be met. The fact that the SSF at the GHTU also demonstrated high maximum removal efficiencies for COD (79%) favours the possibility of supplying an additional SSF. Low budget solutions could also include the application of chlorine which could be added to oxidise pathogens. However it is to mention that the effect of Cl^- on plants is depended on its concentration. Low concentration can limit plant growth and high concentrations can be toxic for plants. This should be carefully evaluated before its application. Threshold values for chlorine concentration need to be considered (see Chapter 5.2).

Figure 35: Visual analysis of greywater from the GHTU. Samples taken 1.5 weeks after filling up of the system and after each of the four treatment steps (ACF, 2013).

Before the laboratory tests were conducted, a visual analysis of the greywater was performed. Samples were taken in clear plastic bottles about 1.5 weeks after complete filling of the GHTU. The samples were taken after each treatment step, thus, sample No.1 is effluent from grease trap, No.2 greywater after septic tank, No.3 after upflow roughing filter and No.4 is collected from the outlet barrel (see Figure 35). The distinct colour in the first samples can be explained through the fact, that the time in between initiation of the GHTU and sampling was too short. About 1.5 weeks do not provide enough time for biological activities to build up sufficiently and perform adequate treatment. However, the effluent from the UFRF (bottle No.3) showed improvement in colour and the last bottle (after SSF) demonstrated clear water with low colour and turbidity.

Table 11: Summarized information about the Greenhouse Treatment Unit (ACF, 2014).

GHTU	Specification
Approach	➔ Mitigate unplanned discharge of greywater by extending treatment period through high temperatures inside the greenhouse ➔ Treated effluent could be used for irrigation in the garden
Scale	Household/Compound
Technical data	Daily flow rate during active treatment in summer: 60l
Set up & Treatment technologies	Pre-treatment → Screen & grease trap Primary treatment → Septic tanks Secondary treatment → Upflow roughing filter Tertiary treatment → Slow sand filter
Treatment processes	Mainly biological (anaerobic) and physical treatment
Operating schedule	Active treatment period (summer) → about 8 months Discharge period (winter) → about 4 months
Operation	During winter: Greywater is discharged During summer: About 60 l/d is fed into the system for treatment
Maintenance	Regular desludging, constructional check-ups, water level controlling, FOG removal, harvesting of vegetation, optional replanting
Monitoring (by ACF)	Sampling, regular constructional checks-ups, user training, communication with user, desludging, cleaning or replacing of filter media, etc.
Effluent quality	Desired: Irrigation standards
Max. overall system removal efficiency	>90%
Mean effluent concentrations	COD: 569 mg/l, TSS: 124 mg/l , NH_4: 15 mg/l, NO_3: 1.9 mg/l , NO_2: 0.07 mg/l, PO_4: <0.9 mg/l, E.coli: 103,000 CFU/100ml
Advantages	Cheap, simple, high removal efficiencies, positive results in other countries
Challenges	Sludge management/disposal, FOG disposal, GW handling in winter
Recommendations	Store water on the compound during winter in form of ice blocks, establishing of synergies with compost project for sludge management, initiation sludge and FOG collecting system, introduction of sludge drying beds

8.2 The Ice Block Unit

Figure 36: Photo of the Ice Block Unit and the household in the background (ACF, 2013).

The design of the IBU is based on the idea that unplanned discharge of greywater is unnecessary during the whole year. In the winter months, the greywater from the household is loaded into the covered storage tank outside, where it accumulates and freezes. The storage tank is designed to receive the calculated amount of GW during the freezing period. When temperatures climb above 0°C the GW melts, experiences pre-treatment and can be transferred to the following purification stages (septic tank and CW). The GW is treated to achieve quality standards allowing irrigation of the vegetation in the garden. The construction of the IBU was completed end of summer 2013. In spring 2014 the system was initiated and accompanied by ACF staff. Sampling was undertaken in October 2014, in addition the treatment potential of the unit is provided on a theoretic base in this study

The combination of compound and treatment technologies are chosen based on various factors that indicated suitability: **(1)** Promising testing of CW for wastewater in northern Mongolia by the UFZ/MoMo project (Integrated Water Resources Management in Central Asia: Model Region Mongolia), **(2)** Sufficient surface area is provided on the compound, **(3)** Owner of the household carries out intensive gardening also including berry bushes and trees, **(4)** User is motivated to be supplied with a new treatment technology, **(5)** The compound has access to a private well which eases the freshwater supply, **(6)** Low slope of the landscape of the compound enables practical implementation, **(7)** Soil conditions are favourable for construction (not rocky). Detailed setup and operation are presented in the following chapters.

8.2.1 Setup and Operation of the Ice Block Unit

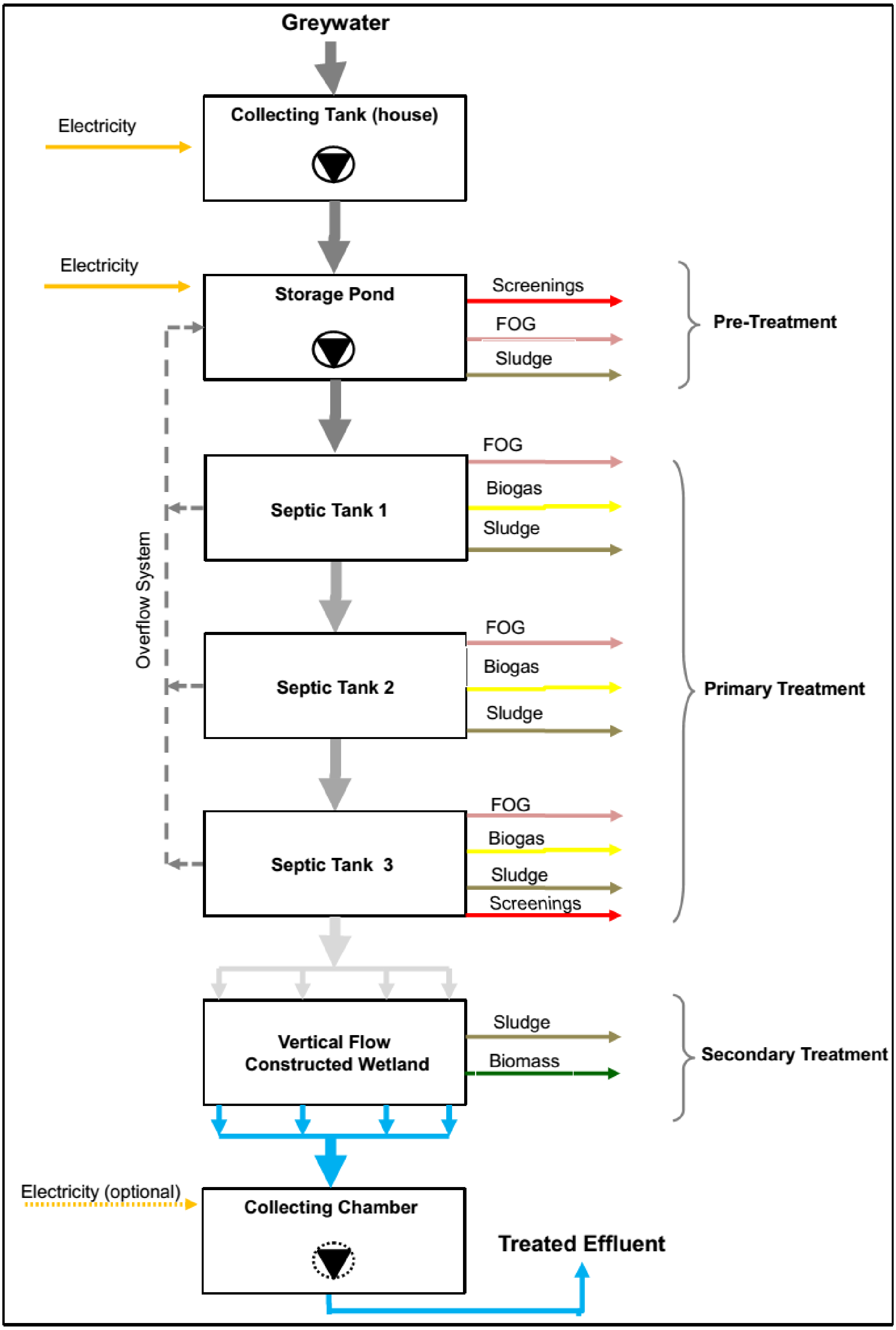


Figure 37: Flowchart of the Ice Block Unit (ACF, 2014).

The **setup** of the IBU consists of three treatment steps, a visualisation of the system is presented in Figure 38 and the flow chart is provided in Figure 37. For a detailed description of the treatment technologies applied see Chapter 6. At the IBU the GW is collected in a barrel inside the house, from where it is pumped to the storage pond. There, the **Pre-treatment** is carried out due to the fact that the GW is provided with sufficient time for a separation of sinking particles and floating FOGs. Since loading is carried out by an electric pump, turbulences might occur. FOGs can be removed though the manhole placed in the frame cover. From the storage pond, the GW is pumped to the septic tank compartments that function as **Primary Treatment.** The septic tanks perform another physical treatment through floatation of FOGs and sedimentation of solid matter. The drums are supplied with sludge outlets on the bottom and reclosable manholes on the lid for FOG removal. Furthermore the drums are connected to an overflow system that evacuates GW back to the storage tank in case of clogging. Due to the fact that the barrels are sealed anaerobic processes occur with resulting biogas production. A specific discharge system for the gas is not foreseen at the IBU since the technologies are located outside. The **Secondary Treatment** step consists of a vertical flow bed constructed wetland which contains gravel as filter media. The treatment step runs subsurface and pollutants are removed mainly through the degradation by microbiological activities and nutrient uptake by the plants. Vegetation grows with ongoing performance and can be harvested periodically and used as biomass for various purposes. The treated GW is transported to a **collecting chamber** through a drainage piping network at the bottom of the CW. The outlet pipe is arranged and fixed in a position that ensures a steady subsurface level of the water. The collecting tank is covered but provided with a manhole through which the treated effluent can be recovered and applied.

The operation of the IBU is scheduled for active treatment for about 4.5 months per year (mid-March – mid-November). During that time temperatures are expected to be above 0°C and steady performance of the IBU is assumed to be possible. The IBU is designed for a treatment capacity of 11,000 litres and a flow rate of 78.6 l/d, which is calculated based on information provided by the user and the following assumptions:

- 3 people live on the compound during winter (7,5 months → 225 days)
- GW production during that time is 3*8 l/d*225d = 5,400l
- 5 people live on the compound during summer (4,5 months → 140 days)
- GW production during that time is 5*8l/d*140d = 5,600l
- Greywater can only be treated during 140 days a year when the temperature is high enough

The total annual greywater production is 11,000l (5,400l + 5,600l) which needs to be treated during 140 days → Flow rate [l/d] = 11,000l/140d = 78.6 l/d.

The IBU is operated primarily by the user. GW is collected in the household and manually fed into the storage pond by an electric pump. From there it is pumped to the septic tank for further treatment. The pumping can be executed by periodically plugging and unplugging the device to supply the septic tanks with the desired volume of about 80 l/d. After this step the water is transported through the system on the base of gravity and pressure (hydrostatic pressure). For the following stages it is not required to provide the system with additional energy but a pump to transport the treated effluent out of the collecting chamber could be added. The volume of the drum in the collecting chamber is about 180l, respectively it is to be emptied every second day.

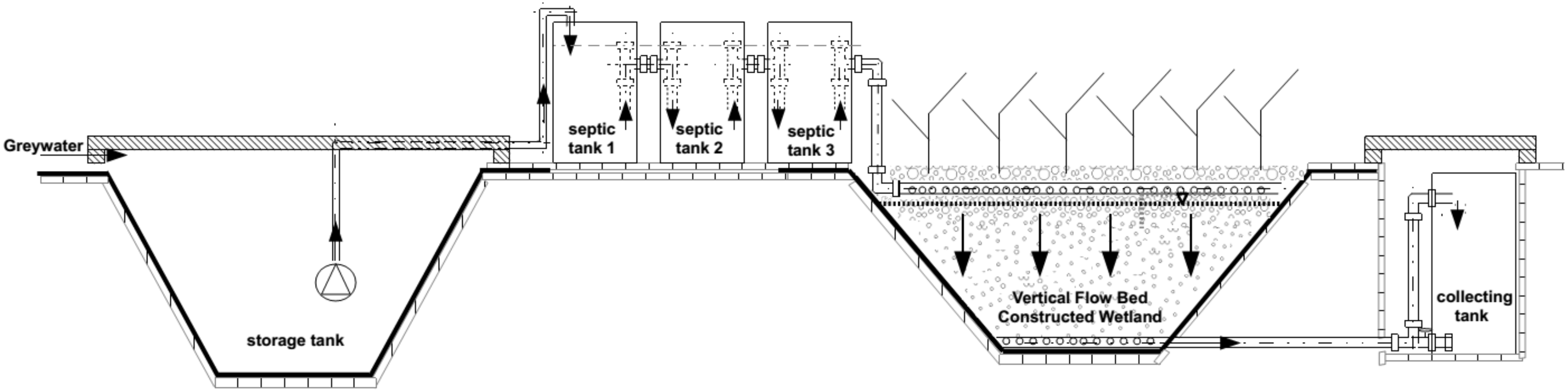


Figure 38: Cross section of the IBU (own design, 2013).

Figure 39: Pictures from the IBU. Covered storage pond in front, septic tanks behind and CW in the back (left). Covered collecting chamber in the front, CW behind, septic tanks left (right) (ACF, 2013).

8.2.2 Theoretic Treatment Potential of the Ice Block Unit

As a laboratory analysis did not exist until October 2014 the treatment potential of the IBU was originally estimated in theory. A calculation of the reduction of selected pollutants is carried out in Table 12. The removal rates represent literature values for the specific technology (also see Chapter 6). The influent values represent maximum concentrations from the sampling data from GW at the GHTU in 2013. If ranges of removal rates are provided, the calculation was undertaken with the lowest value. Based on the fact that the technologies are arranged in series, the effluent values of the previous treatment step represent the influent values of the following stage. The effluent concentrations of the CW represent the GW quality of the effluent of the IBU. The results provided effluent concentrations that meet various guidelines for unrestricted irrigation as presented in Chapter 5.2.

Table 12: Calculated theoretic performance of the Ice Block Unit (ACF, 2014).

Storage Pond		**Septic Tank**		**Vertical Flow Bed CW**	
Influent Quality					
COD [mg/l]	4,824	COD [mg/l]	482.4	COD [mg/l]	361.8
TSS [mg/l]	1484	TSS [mg/l]	296.8	TSS [mg/l]	178.1
NH_4 [mg/l]	329	NH_4 [mg/l]	329	NH_4 [mg/l]	111.9
PO_4 [mg/l]	12.3	PO_4 [mg/l]	4.43	PO_4 [mg/l]	1.95
E.coli [CFU/100ml]	810,000	E.coli [CFU/100ml]	243,000	E.coli [CFU/100ml]	24,300
Removal efficiency					
[2]COD [%]	90	[1]COD [%]	25-50	[1]COD [%]	90
[2]TSS [%]	80	[1]TSS [%]	40-60	[1]TSS [%]	90-99
NH_4 [%]	n.a.	[4]NH_4 [%]	66	[1]NH_4 [%]	90
[2]PO_4 [%]	64	[4]PO_4 [%]	56	[3]PO_4 [%]	35
[2]E.coli [%]	70	[1]E.coli [Log unit]	1	[1]E.coli [Log unit]	3
Resulting Effluent Quality					
COD [mg/l]	482.4	COD [mg/l]	361.8	COD [mg/l]	36.2
TSS [mg/l]	296.8	TSS [mg/l]	178.1	TSS [mg/l]	17.8
NH_4 [mg/l]	329	NH_4 [mg/l]	111.9	NH_4 [mg/l]	11.2
PO_4 [mg/l]	4.43	PO_4 [mg/l]	1.95	PO_4 [mg/l]	1.27
E.coli [CFU/100ml]	243,000	E.coli [CFU/100ml]	24,300	E.coli [CFU/100ml]	24.3

[1](Schüssler, 2010), [2](CWP, 2007), [3](Meulemann, 2003), [4](own data, 2013)

8.2.3 Performance of the Ice Block Unit

As the theoretic treatment potential was demonstrated, weekly samples were taken at the IBU in October 2014. A series of four water quality tests were carried out. In addition to weekly quality tests for influent and effluent, samples were also analysed after each treatment step (see Chapter 6 for removal rates of the treatment technologies applied). A chemical analysis was carried out for the pollutants COD, TSS, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, while E.coli was tested as biological parameter. The specific contaminants were chosen as common representatives for physical, chemical and biological pollution. All parameters (except BOD_5), recommended by UN-Habitat (UN-Habitat, 2008), that are necessary to assess the performance of a CW are represented in this study. The laboratory analysis was performed by the Environmental Metric Central Laboratory in Ulaanbaatar. The system's performance, indicated by influent and effluent values, is presented graphically in the following figures and is discussed below. Sampling data needs to be considered critically based on the factors described in Chapter 8.1.3

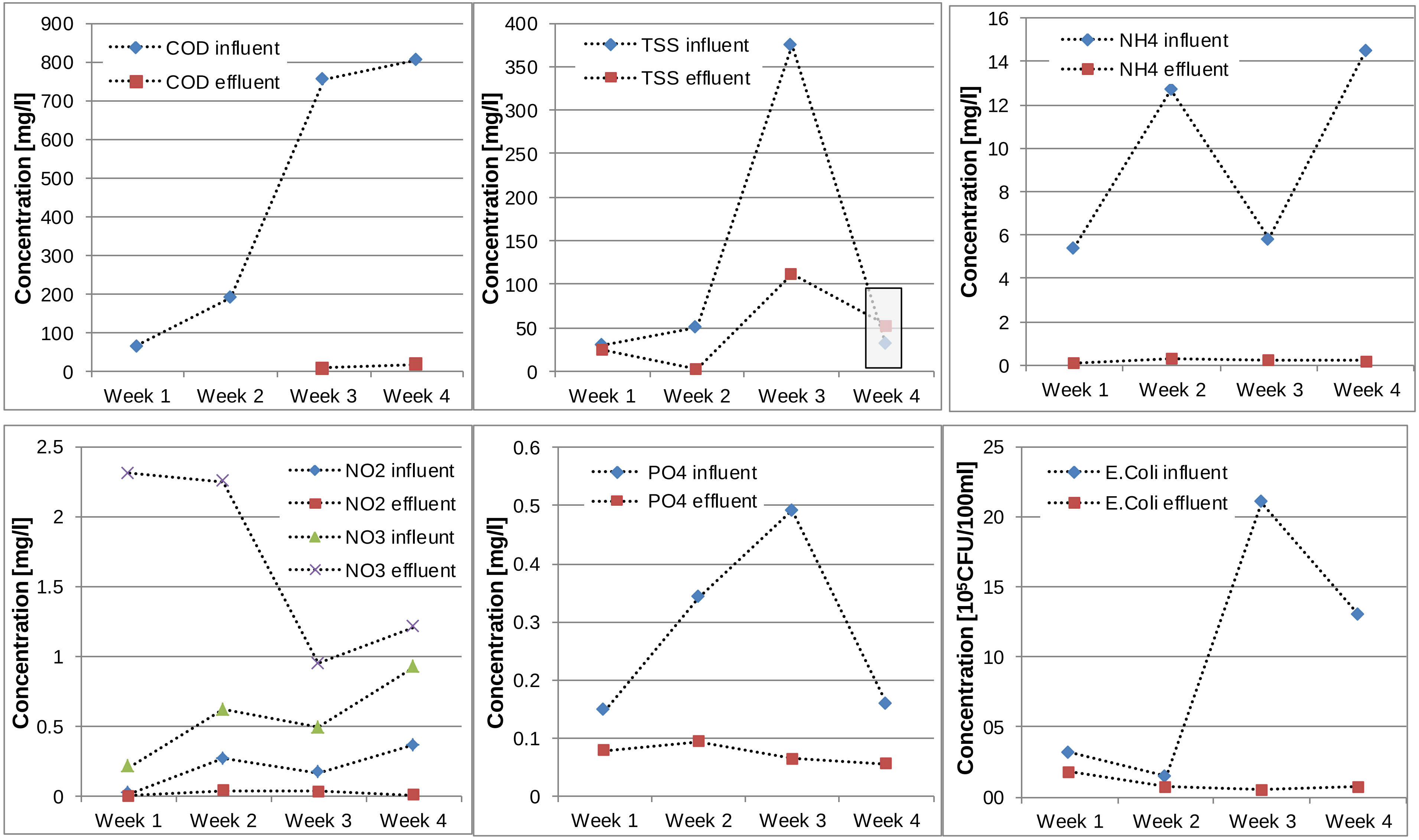


Figure 40: Influent and effluent concentration of COD, TSS, NH_4, NO_3, NO_2, PO_4 and E.coli from a sampling series in Oct. 2014 at the IBU (ACF, 2014).

The COD concentration of the influent varies from 66.9-808.4 mg/l, while effluent values range from 9.6-19.2 mg/l. Effluent values for week three and four are not provided. The maximum removal rate of COD is reached in week three and accounts to 99% demonstrating very high removal potential of the unit. Mean effluent value is 14.4 mg/l, which can be considered low, meeting COD standards applied in Israel (see Chapter 5.2).

The concentrations of TSS in the influent range between 30.4-375 mg/l, while TSS in the greywater from the outlet ranges from 3.2 to 112 mg/l. The fact that the influent value is lower than the effluent concentration is assumed to be related to an exchange of the samples and therefore it is not considered any further. Even if TSS influent concentrations vary greatly the system still performs a reduction to comparably steady levels. The maximum removal rate for TSS (week 2) is 94%. The mean effluent concentration is 46.9 mg/l, which is below the required standards for unrestricted irrigation in India and Portugal in this study (see Chapter 5.2).

NH_4 values from influent range from 5.4-14.5 mg/l, whereas the treated samples lie in the range of 0.1-0.3 mg/l. Maximum removal of 99% is achieved in week four. Mean effluent concentration is 0.2 mg/l which is lower than the threshold values from Israel and India for unrestricted irrigation (see Chapter 5.2).

Influent concentrations for NO_3 range from 0.21-0.92 mg/l, while effluent values lay between 0.95-2.13 mg/l. The fact that NO_3 in the effluent is higher than in the influent can be explained through nitrification. The IBU operates aerobically as the system is not sealed and oxygen enters the biological treatment step through the surface of the VFCW. Under these conditions nitrification, a two-step reaction from NH_4 to NO_3 takes place. During the first reaction NH_4 is converted into the intermediate product NO_2, in the second step NO_2 is transformed to NO_3. NH_4 entering the system is converted by nitrifying bacteria which results in exceeding effluent concentrations of $NO_{3.}$ Therefore negative removal rates can occur. Nitrification is quicker than denitrification, consequently the intermediate product NO_2 exists for a limited time and does not remain in the effluent as much as at the GHTU. Mean effluent concentration of NO_3 remains low with 1.7 mg/l, which meets minimum requirements for irrigation standards in Portugal (see Chapter 5.2). Nitrite values in of the influent range between 0.02 and 0.36 mg/l, the effluent concentration range from 0.004-0.04 mg/l. The maximum removal rate is achieved in week four and accounts to 93%. The mean effluent concentration remains very low with 0.02 mg/l and Syrian irrigation standards are met (see Chapter 5.2).

Influent values of PO_4 range from 0.15-0.49 mg/l, while effluent concentrations lie between 0.06-0.09 mg/l. In terms of PO_4 removal efficiency, a maximum rate of 87% is achieved.

Effluent concentrations are constantly below 0.09 mg/l and even meet the strict standards for unrestricted irrigation in Israel (see Chapter 5.2).

E.coli concentrations from the influent vary from 130,000 to 2,100,000 CFU/100ml for, the treated samples range from 71,000-140,000 CFU/100ml. Even with a maximum removal rate of 98%, the mean effluent concentration remains rather high (92,000 CFU/100ml) and exceeds the standards for unrestricted irrigation referred to in this study. It is to mention though that WHO standards on restricted irrigation are met, as in this guideline threshold values are 100,000 CFU/100ml (in the case of limited exposure or if regrowth is likely (see Chapter 5.2)).

The overall performance of the GHTU provides very satisfying results with maximum removal rates exceeding 87% for all separate parameters (excluding NO_3). The fluctuations of the removal efficiencies can be explained with highly varying influent compositions and different daily GW production resulting in irregular hydraulic retention times. All tested parameters except E.coli meet standards for unrestricted irrigation as provided in Chapter 5.2. However, E.coli concentration is lower than the requirements for restricted irrigation by the WHO (see Chapter 5.2). A low budget solution to reduce pathogens could include the application of chlorine, but concentrations have to be considered carefully (see Chapter 8.1.3). Even in comparison to the theoretic treatment potential (see Chapter 8.2.2) the IBU provided higher mean effluent concentrations for all parameters except TSS and E.coli.

Table 13: Summarised information about the Ice Block Unit (ACF, 2014).

IBU	Specification
Approach	➔ Prevent unplanned discharge of greywater by storing in winter and treatment in summer. ➔ Treated effluent can be used for irrigation in the garden
Scale	Household/Compound
Technical data	Daily flow rate during active treatment in summer: 78.6l
Set up & Treatment technologies	Pre-treatment → Storage pond Primary treatment → Septic tanks Secondary treatment → Vertical Flow Bed Constructed Wetland
Treatment processes	Mainly biological (anaerobic) and physical treatment
Operating schedule	Active treatment period (summer) → about 4.5 months Passive storage period (winter) → about 7.5 months
Operation	During winter: greywater is pumped from the household to the storage pond During summer: About 80 l/d is pumped to from the storage pond to the septic tank for treatment
Maintenance	Regular desludging, constructional check-ups, water level controlling, FOG removal, harvesting of vegetation, optional replanting
Monitoring (by ACF)	Sampling, regular constructional checks-ups, user training, communication with user, desludging, cleaning or replacing of filter media, etc.
Effluent quality	Desired: Irrigation standards
[1]**Max. overall system removal efficiency**	95%
Mean effluent concentrations	COD: 14.4 mg/l, TSS: 46.9 mg/l , NH_4: 0.2 mg/l, NO_3: 1.7 mg/l , NO_2: 0.07 mg/l, PO_4: <0.09 mg/l, E.coli: 71,000 CFU/100ml
Advantages	Cheap, simple, high removal efficiencies, positive results in other countries, whole year prevention of unplanned GW disposal
Challenges	Sludge management/disposal, FOG disposal, habitat for mosquitos, odour, rainwater feeding the system, difficulties with regulating the daily flow with the pump, large surface area requirements
Recommendations	Store water on the compound during winter in form of ice blocks, establishing of synergies with compost project for sludge management, initiation sludge and FOG collecting system, introduction of sludge drying beds

[1](excluding NO_3),

9 Operation, Maintenance and Monitoring Guidelines of the Greywater Treatment Units

Proper operation, maintenance and monitoring of the GWTUs are crucial for their successful performance. If these actions are not adequately considered a failure of the system is likely to occur as indicated by the evaluation of the GWTUs from 2010. Apart from the technological shortcomings of the previous systems, it was identified that they failed due to a lack of understanding of the operational principles by the user and deficient maintenance and monitoring by ACF.

On the basis of lesson learnt this chapter presents detailed guidelines for operation, maintenance and monitoring of the GWTUs, including the distribution of responsibilities between the actors involved. All technologies applied require specific handling in terms of type of action (‘what to do’), temporal arrangement (‘when to do it‘), frequency (‘how often to do it’) and executing actor (‘who does it’). Daily operations on site are carried out by the user, major maintenance is executed jointly by user and ACF, while monitoring is the exclusive responsibility of ACF (greywater manager if available). The overall responsibility of the GWTUs is covered by ACF and supervision and guidance should be carried out on the base of this study. At the end of each of the following subchapters, tables are provided that imply summarised actions with a detailed distribution of the areas of responsibility. The tables can be regarded as a logbook that lists all scheduled actions required for a proper functioning of the systems. The guidelines should be translated into Mongolian and handed over to the user.

It is to mention that the guidelines are limited in terms of waste handling/sludge disposal. Until improved handling options are elaborated, recovered solids, sludge or FOGs can be either burned on site or disposed with the household garbage. Liquid disposals can be discharged into the soak pit. The author emphasises that these actions are not recommended and only serve as non-optimal solution for the moment (also see Chapter 10). In the future a collecting service (with transport to the WWTP) for the liquid discharges should be initiated. Composting of the organics can be a benefiting option (create synergies with composting project) or the application of simple drying beds for sludge where space is available. In case the significance of biogas in Mongolia increases, organics (FOGs, solids from screen, sludge, etc.) can be used as an energy resource. This could be relevant in a context beyond this study.

9.1 Operation, Maintenance and Monitoring Guidelines for the Greenhouse Treatment Unit

9.1.1 Screen

Daily:

- ➔ Remove food residues and other particles from the mesh of the screen
- ➔ Dispose with the household garbage

Monthly:

- ➔ Check condition of the screen (permeability, wooden frame, etc.)

Yearly:

- ➔ Replace screen for a new one

9.1.2 Grease Trap

Weekly:

- ➔ Check if pipes are leaking and accordingly fixed
- ➔ Check water level in the tank to ensure no clogging occurs

Remove FOGs:

- ➔ Open manhole on the lid
- ➔ Use ladle (provided) to skim the FOGs from the top layer of the water surface
- ➔ Dispose FOGs with household garbage or burn it on site

Monthly:

Cleaning of outlet pipes:

- ➔ Clean outlet pipes from the top to remove FOGS that can cause clogging
- ➔ Use a small brush attached to a stick (not provided yet)

Twice per year:

Desludging:

- ➔ Prepare buckets underneath the plug valves on the bottom of the drum

- ➔ Open plug valve carefully to slowly release sludge containing greywater into a bucket
- ➔ Release about 20% of the volume of the septic tank
- ➔ Discharge sludge with household garbage

Sampling: see 9.1.6

Every two years:

Clean grease trap:

- ➔ Prepare buckets underneath the sludge outlets of the grease trap
- ➔ Empty barrels by opening the plug valves
- ➔ Clean the drums inside, use fresh water

9.1.3 Septic Tank

Weekly:

- ➔ Check if pipes are leaking and accordingly fixed
- ➔ Check water level in the tank to ensure no clogging occurs

Twice per month:

Remove FOGs:

- ➔ Open manhole on the lid
- ➔ Use ladle (provided) to skim the FOGs from the top layer of the water surface
- ➔ Dispose FOGs with household garbage or burn it on site

Monthly:

- ➔ Clean outlet pipes from the top to remove FOGS that can cause clogging
- ➔ Use a small brush attached to a stick (not provided yet)

Twice per year:

Sampling: see 9.1.6

Yearly:

Desludging:

- ➔ Prepare buckets underneath the plug valves on the bottom of the drum
- ➔ Open plug valve carefully to slowly release sludge containing greywater into a bucket
- ➔ Release about 20% of the volume of the septic tank

- ➔ Discharge sludge with household garbage

Every two years:

Clean septic tank:

- ➔ Prepare buckets underneath the sludge outlets of the septic tank
- ➔ Empty septic tanks by opening the plug valves
- ➔ Clean the drums inside, use fresh water

9.1.4 Upflow Roughing Filter

Weekly:

- ➔ Check if pipes are leaking and accordingly fixed
- ➔ Check water level in the tank to ensure no clogging occurs

Twice per year:

Sampling: see 9.1.6

Yearly:

Desludging:

- ➔ Disconnect the UFRF
- ➔ Empty it through the plug valves at the bottom
- ➔ Discharge sludge with household garbage
- ➔ Use manhole to flush the filter with clean water with buckets
- ➔ Discharge effluent through sludge outlet with household garbage

Every two years:

Remove and clean filter media:

- ➔ Disconnect the UFRF
- ➔ Empty it through the plug valves at the bottom
- ➔ Discharge sludge with household garbage
- ➔ Use manhole to remove filter media for
- ➔ Thoroughly clean gravel with freshwater
- ➔ Refill the drums with clean filter media

9.1.5 Slow Sand Filter

Weekly:

Check water column on top of filter bed:

- ➔ Check that water level in the filter is about 5cm (use measuring device)
- ➔ If water level rises towards the overflow, remove the Schmutzdecke layer to prevent clogging
- ➔ Check if system is leaking (overflow, inlet pipe, outlet pipe)

Monthly:

Remove Schmutzdecke:

- ➔ Disconnect the SSF from the system by closing the plug valve at the inlet pipe
- ➔ Open manhole on top of the drum
- ➔ Lower outlet pipe by about 10cm to drain the filter and to expose the top layer.
- ➔ Carefully scrap off the Schmutzdecke (about 2cm) until new sand layer is exposed, use flat scraper (not provided yet)
- ➔ Discharge organic removals with household garbage
- ➔ Re-adjust height of the outlet pipe in a position that top sand layer will be covered by a water column of 5cm
- ➔ Open plug valve at inlet pipe again
- ➔ It takes about 2 days for the MOs to redevelop, so the effluent during that time should be refilled into the sink of the GHTU

Twice per year:

- ➔ **Sampling:** see 9.1.6

Every two years:

Re-sand the filter units:

- ➔ Disconnect the SSF from the system by closing the plug valve at the inlet pipe
- ➔ Release water through sludge outlet
- ➔ Empty the barrel of the sand and dispose it
- ➔ Apply new washed middle coarse sand to provide new filter media

9.1.6 Whole System

Daily:

- Feed system with about 60 l/d
- Empty collecting tank

Twice per month:

Technical observation and communication:

- ACF staff site visit including technical observation and communication with user about state and performance of GHTU and possible concerns, etc.
- Check whole system (including venting system, inlet, effluent tank, overflow system, etc.) for leakages, technical shortcomings, plugging, etc.

Twice per year:

Sampling to assess treatment unit performance:

- Samples to be taken after each treatment step
- 5 weekly samples over 4 weeks
- 2 sampling series should be undertaken
- One series about 1 month after initiating the system (beginning of May) and one series about 2 weeks before shut down for winter period (mid-October)
- Parameters should include: COD, TSS, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-} and E.coli
- Analyse ongoing performance of the unit
- Apply optional adjustments accordingly

Yearly:

Initiation around the beginning of spring:

- Start checking temperature inside the greenhouse mid-March
- As soon as temperatures are high enough (>0°C) during night system can be initiated (expected around April 1st)

Shut down in winter:

- Start checking temperature inside the greenhouse mid-October
- As soon as temperatures drop below 0°C during night system should be shut down (expected around November 1st)

User training:

Before the system is initiated, ACF should provide a comprehensive on-site training for the user (and a plumber) on the basis of this thesis. The 1-2 days introductory course should be executed by the greywater manager and includes:

- ➔ Knowledge transfer of the importance and the benefits of greywater treatment
- ➔ Explanation of the technical installation and the treatment process to the user
- ➔ Instructions about the operation of the system
- ➔ Provide operation supervision schedule
- ➔ Handover of the user guidelines
- ➔ Discussion with user

Every two years:

Overall Evaluation by ACF in form of a report:

- ➔ Evaluation of performance of the unit
- ➔ Analysis of possible technological short-comings
- ➔ Development of proposals for technical and operational improvements
- ➔ Implementation of adjustments on the base of lesson learnt

Table 14: User-, maintenance- and monitoring- 'logbook' for the GHTU (ACF, 2014).

	Daily	Weekly	Twice per month	Monthly	Twice per year	Yearly	Every two years
Screen	Remove Food residues & other particles	X	X	Check condition	X	X	Apply new screen
Grease Trap	X	Check for leakages Check water level inside the drum Remove FOGs	X	Cleaning of outlet pipes	Sampling Desludging	X	Empty barrels and clean inside
Septic Tank	X	Check for leakages Check water level	Remove FOGs	Cleaning of outlet pipes	Sampling	Desludging	Empty barrels and clean inside
UFRF	X	Check for leakages Check water level	X	X	Sampling	Desludging	Remove and clean filter media
SSF	X	Check for leakages Check water column on top sand layer	X	Remove Schmutzdecke	Sampling	X	Re-sand the SSF
Whole system	Feed system with about 60 l/d Empty collecting tank	X	Technical observation and communication	X	Sampling Analysis of the performance	Initiation in spring Shut down in winter User training Update logbook	Overall Evaluation

Green: Action executed by user; Blue: Action jointly executed; Yellow: Action executed by ACF staff (greywater manager and/or plumber + daily worker)

9.2 Operation, Maintenance and Monitoring Guidelines for the Ice Block Unit

9.2.1 Storage Pond

Daily (all year):

Charging of the pond with GW from the household

Daily (during summer):

Feeding treatment system:

- ➔ Prepare pump and open manhole on the cover of the tank
- ➔ Pump about 80 l/d of greywater from the cleaner middle layer to the septic tanks
- ➔ Use ‘plug-in & out’ technique of the pump to determine the flow and flow rate
- ➔ Use septic tank volume as reference for daily flow
- ➔ About ½ volume of the septic tank should be fed per day

Weekly:

- ➔ Overall check-up of the pond including cover, PVC liner, etc.

Monthly:

Remove FOGs:

- ➔ Open manhole on the cover of the pond
- ➔ Use bucket attached to a wooden stick/bar (not provided) to skim the FOGs from the top layer of the water surface
- ➔ Dispose FOGs with household garbage or burn it on site

Twice per year:

Sampling: see 9.2.5

Yearly:

Desludging:

- ➔ Before switching the system into passive storage mode it has to be desludged
- ➔ Storage pond should contain low greywater volumes at that point
- ➔ Prepare pump and locate it at the bottom of the storage pond

- ➔ Pump out the about sludge until about 10cm is left (for protection)
- ➔ Discharge sludge

9.2.2 Septic Tank

Weekly:

- ➔ Check if pipes are leaking and accordingly fixed
- ➔ Check water level in the tank to ensure no clogging occurs

Twice per month:

Remove FOGs:

- ➔ Open manhole on the lid
- ➔ Use ladle (provided) to skim the FOGs from the top layer of the water surface
- ➔ Dispose FOGs with household garbage or burn it on site

Monthly:

- ➔ Clean outlet pipes from the top to remove FOGS that can cause clogging
- ➔ Use a small brush attached to a stick (not provided yet)

Twice per year:

Sampling: see 9.2.5

Yearly:

Desludging:

- ➔ Prepare buckets underneath the plug valves on the bottom of the drum
- ➔ Open plug valve carefully to slowly release sludge containing greywater into a bucket
- ➔ Release about 20% of the volume of the septic tank
- ➔ Discharge sludge with household garbage

Every two years:

Clean septic tank:

- ➔ Prepare buckets underneath the sludge outlets of the septic tank
- ➔ Empty septic tanks by opening the plug valves
- ➔ Clean the drums inside, use fresh water

9.2.3 Vertical Flow Bed Constructed Wetland

Weekly:

General check:

- Check if water level of the bed is constant
- Use measuring device to check from top of the bed
- Observe constant daily flow rate of effluent

Twice per year:

Sampling: see 9.2.5

Yearly:

Harvesting of plants:

- Undesired plants can be harvested towards the end of the year
- Discharge plants with compost

Replanting if necessary

Optional cleaning of piping networks:

- Prepare high pressure pump
- Apply pump at the opening of the outlet pipe
- Flush drainage system and clear away possible clogging

Every two years:

Remove and clean filter media:

- Drain the filter bed by opening the plug valve at the outlet pipe
- Discharge effluent
- Remove filter media
- Thoroughly clean gravel with freshwater
- Refill the drums with clean filter media

9.2.4 Collecting Chamber

Daily:

- Empty collecting tank

Weekly:

- ➔ Check if pipes are leaking
- ➔ Check adjustment and height of outlet pipe

Monthly:

- ➔ Check walls for stability
- ➔ If cracks or leaks appear, fix immediately

Yearly (end of active treatment):

- ➔ Close plug valve at outlet pipe
- ➔ Empty barrel

9.2.5 Whole System

Daily (during summer):

- ➔ Feed treatment system with about 80 l/d
- ➔ Empty collecting tank

Daily (during winter):

- ➔ Pump greywater from household to storage pond

Twice per month:

Technical observation and communication:

- ➔ ACF staff site visit including technical observation and communication with user about state and performance of GHTU and possible concerns, etc.
- ➔ Check whole system (including venting system, inlet, effluent tank, overflow system, etc.) for leakages (especially in the PVC liner), technical shortcomings, plugging, etc.

Twice per year:

Sampling to assess treatment unit performance:

- ➔ Samples to be taken after each treatment step
- ➔ 4 weekly samples over 4 weeks
- ➔ 2 sampling series should be undertaken
- ➔ One series about 1 month after initiating the system (beginning of May) and one series about 2 weeks before shut down for winter period (mid-October)

- ➔ Parameters should include: COD, TSS, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-} and E.coli
- ➔ Analyse ongoing performance of the unit
- ➔ Apply optional adjustments accordingly

Yearly:

Initiation of ‘active treatment mode’ around the beginning of April:

- ➔ Start checking temperature on compound mid-March
- ➔ As soon as temperatures are high enough (>0°C) during night system can be initiated (expected around April 1st)

Switch to ‘passive storage mode’ around October:

- ➔ Start checking temperature on the compound mid-October
- ➔ As soon as temperatures are high enough (>0°C) during night system can be initiated (expected around November 1st)

User training: see 9.1.6

Every two years:

Overall evaluation by ACF in form of a report:

- ➔ Evaluation of performance of the unit
- ➔ Analysis of possible technological short-comings
- ➔ Development of proposals for technical and operational improvements
- ➔ Implementation of adjustments on the base of lesson learnt from operation

Table 15: User-, maintenance- and monitoring- ‘logbook’ for the IBU (ACF, 2014).

	Daily	Weekly	Twice per month	Monthly	Twice per year	Yearly	Every two years
Storage Pond	(all year) charging of the pond (summer) feeding of treatment system	Overall check up	X	Remove FOGs	Sampling	Desludging	X
Septic Tank	X	Check for leakages Check water level	Clean outlet pipes	Remove FOGs	Sampling	Desludging	Empty barrels and clean inside
VFB CW	X	Overall check up	X	X	Sampling	Harvesting (optional) replanting	Remove and clean filter media
Collecting chamber	Empty barrel	Check for leakages Check outlet pipe	X	Check walls	Sampling	Empty collecting tank	X
Whole system	(summer) Feed system with about 80 l/d (summer) Empty collecting tank (winter) feed storage pond	X	Technical observation and communication	X	Sampling Analysis of the performance	(spring) Initiation of ‘active treatment mode’ (winter) Switch to ‘passive storage mode’ User training Update logbook	Overall evaluation

Green: Action executed by user; Blue: Action jointly executed; Yellow: Action executed by ACF staff (greywater manager and/or plumber + daily worker)

10 Discussion

The purpose of this study is to identify the technical feasibility of decentralised GWTUs in order to improve sanitation in the ger area of UB by mitigating the unplanned discharge of greywater. As greywater in that area is heavily polluted and climate is extremely cold it was to asses if customized low-tech small scale treatment systems are able to perform satisfying purification under these conditions. The two units applied are designed to produce an effluent quality that allows irrigation on the user's private compound. To supply adequate treatment the GWTUs consisted of multiple purification steps including biological processes for pathogens reduction.

It is demonstrated that the research field provided a unique local context including e.g. harsh climate conditions, water shortages, sanitation, water distribution or impacts on health through water borne diseases. Data collected in the context of this research confirms that greywater from Mongolia's ger districts is heavier polluted than in most other countries. On the basis of previously installed treatment systems in the ger district two units are implemented, the GHTU and the IBU. Both systems follow the same approach but imply different technologies and concepts. The individual treatment technologies applied at the GWTUs are adjusted according to the specific local settings of the research field. The GHTU provides three treatment steps and is placed in a greenhouse. By taking advantages of higher temperatures inside the GH the period of active treatment can be extended. It operates under anaerobic conditions and its surface area requirements are low in comparison to the IBU. The IBU enables a prevention of unplanned discharges throughout the whole year by storing the greywater during the winter. The system applies aerobic treatment and consists of three treatment steps.

Both GWTUs presented in this paper demonstrated great potential to improve sanitation in the ger area of UB. Even that the systems had to overcome challenging factors such as cold climates or heavily polluted influents their performance is considered satisfying in terms of stability, removal efficiencies and effluent quality. Greywater at the GHTU was heavier polluted in comparison to the IBU. As concentrations were higher at the GHTU, mean effluent values exceeded those at the IBU. At the GHTU all parameters tested met unrestricted irrigation standards except E.coli and COD. In order to achieve required threshold values for restricted irrigation for COD and E.coli a slow sand filter could be added to the system. In that case effluent could be used for the irrigation of trees or berry bushes located on the compound where requirements are lower (see Chapter 8.1.3). Mean effluent values at the IBU met standards for unrestricted irrigation except E.coli. If no further treatment is added the effluent could be used for restricted irrigation which requires limited exposure or regrowth has to be assumed (see Chapter 5.2). In order to meet standards that allow irrigation of crops eaten raw, a low budget solution could be provided by adding chlorine to the effluent (see Chapter 8.2.3). More detailed discussion about the performance of the GWTUs is provided in Chapter 8.1.3 and Chapter 8.2.3.

Although great potential of the treatment unit has been demonstrated some challenges that evolved during the progress of this research could not be solved, clarified or integrated in this study (exceeded the scope). In the following some relevant shortcomings of this thesis are discussed. Open questions evolving from this may require further investigation and can be regarded as possible future research projects.

Constructional shortcomings: During construction of the GWTUs shortcomings came up that might have impact on the long term performance of the systems. **(1)** The PVC liner at the IBU is very thin and respectively vulnerable for cracks. In addition the upper surface was not covered with a protection layer of sand which may lead to damages caused by the filter media. Even though the gravel applied has rather round shape, leakages are to be observed. The specific membrane was chosen due to its low costs, but pricier and more robust alternatives can be considered for future constructions. **(2)** The storage pond is covered but not completely sealed. This may result in the production of unpleasant odours affecting the nearby household. The pond could be sealed from the top and supplied with a venting system evacuating odours. Resulting anaerobic conditions in the pond need to be considered. **(3)** Evaporation losses of storage pond and CW are not particularly evaluated. However it is expected to be low under given climate conditions. **(4)** Rainwater might enter the storage pond and the CW. Possible dilution effects are not considered. **(5)** Screen is not installed at the IBU which may lead to high organic loads in the storage pond. **(6)** As pre-screened sand is not available in UB grain sizes applied at the SSF might be too fine. The risk of clogging is particularly high in this case.

Conceptual shortcomings: **(1)** The parameters to evaluate the performance of the unit or to determine the applicability for irrigation are limited in this paper. Various indicators such as electrical conductivity, pH, heavy metals, non-degradable chemical components or Sodium Absorption Reason (SAR) are not considered, even though they may correspond negatively to health, soil properties and plant growth. For adequate irrigation suggestions these parameters should be taken into account. **(2)** The types of detergents and cleaning chemicals used in the ger area were not identified. Ingredients from these products can have negative impact on the treatment systems. **(3)** The management/disposal of sludge/FOGs is not elaborated, but indicates high relevance in the context of this research. Unplanned discharges promote the accumulation of pollutants into the environment which may depreciate most benefits evolving from the GWTUs. Therefore a collecting service (with transport to the WWTP) for the liquid discharges could be initiated. Composting of the organics can also be a suitable option (synergies with ACF-composting projects recommended) or the application of simple drying beds for sludge where space is available. **(4)** The amount of time required to melt around 5,400 litres of greywater in the storage tank after winter is not considered. Due to occurring night-frosts in spring the initiation of the active treatment of the IBU could be delayed. Low temperatures during night may also have impacts on the performance of the GHTU after initiation in spring. **(5)** The correlation between temperature and removal rate is not considered in this study. **(6)** In terms of reasonability for the user it may be discussed that the GWTUs require certain amount of time for operation and maintenance that are not negligible. Benefits may not have been communicated adequately to the user during the time of construction.

Further shortcomings: (1) As this paper focuses on the technical feasibility of the GWTUs social or economic aspects are not broadly represented. For a holistic approach they should be taken into account to determine e.g. social acceptance or economic inadequacy of the systems. Further ACF-master theses in that research context are recommended to include these aspects. **(2)** The sampling data should be considered carefully since various factors could have negatively impacted the quality of the results (see Chapter 8.1.3).

11 Conclusion

This thesis clearly demonstrated the technical feasibility of decentralised low-tech GWTUs which therefore provide great potential to improve sanitation in the peri-urban areas of Ulaanbaatar. Although effluent concentrations did not always meet the strict guidelines for unrestricted irrigation a significant reduction of pollutants is achieved. This indicates that the soil and groundwater pollution can be minimised by the systems and therefore health hazards for ger area residents can be mitigated.

Since the units applied in this study represent pilot treatment systems it is expected that performances can be improved in the future by optimising operation, processes or maintenance. Beyond that further on-site treatment systems should be tested. The GWTUs in this paper are adapted to the specific local settings of the compounds, but different decentralised designs could be more suitable for other sites.

However, household level treatment units may not be the exclusive approach to improve the sanitary situation. Upscaling of the treatment systems could be a promising option for the future. By connecting more people to a GWTU higher treatment efficiencies could be achieved and operating-/maintenance pressure on the user could be decreased. Apart from those advantages, evolving challenges such as adequate (safe & convenient) transport of greywater still need to be addressed.

Even though greywater reuse includes the benefit of directly mitigating the water stress in the study area, discharge system should also be considered more intensively. Subsurface infiltration systems such as infiltration trenches or beds could provide less cost intensive alternatives as standards are lower and, accordingly, technical expenses. With this approach greywater could be disposed in controlled manner and through possible groundwater recharge the effluent could be reused ‘indirectly’.

In the long term the great potentials coming along with greywater should be considered more carefully. For instance the heavy organic loading of greywater in the ger area indicates its high energy potential. In a context beyond this research greywater could be used as energy source in biogas plants. Also synergies with composting projects should be established as treated sludge could be used to improve soil conditions in agriculture.

In summary it is to say that it is a long way to overcome water scarcity and environmental pollution, but the promising results of this research demonstrate that the approach of decentralised GWTUs should be carried on. It is to hope that this thesis can contribute to future improvements of the sanitary situation in Ulaanbaatar’s ger areas and other peri-urban regions in Mongolia.

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