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PHD THESIS

A Study on Sustainable Sanitation Technologies for Vulnerable Peri-Urban Communities in Ulaanbaatar, Mongolia

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PhD Report

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A STUDY ON SUSTAINABLE SANITATION TECHNOLOGIES FOR VULNERABLE PERI-URBAN COMMUNITIES IN ULAANBAATAR, MONGOLIA

ABSTRACT

In many of the world's undeveloped or partially-developed countries, and even in some developed ones, frequent outbreaks of various water, sanitation and hygiene (WASH)- and greywater-borne diseases are still prevalent due to lack/absence/failure of WASH system. As a result, poor sanitation accounts for the death of a child every 20 seconds which leads to 1.5 million preventable death each year. Therefore development of alternative sanitation technologies which are sustainable can be a problem-solver in the field of WASH, can be one of the options to tackle the WASH- and greywater- borne challenges around the world including Mongolia. This study was carried out for the first time in the coldest capital in the world, namely Ulaanbaatar, Mongolia during the period of 2012 and 2014 to assess technical feasibility, replicability and social acceptability of various sustainable sanitation technologies (e.g. eco-toilets, greywater and human feces treatment technologies) for the vulnerable communities.

The results from Ice-Block Greywater Treatment Unit (IB-GWTU) show that the maximum removal rates of chemical oxygen demand (COD), NH4+, NO2-, total suspended solid (TSS), PO4-, and Escherichia coli were up to 98%, 99%, 97%, 97%, 87%, and 98% respectively. As for Greenhouse Greywater Treatment Unit (GH-GWTU), the maximum removal rate of over 90% of those parameters was achieved. Both technologies have high potential to significantly reduce chemical and biological contaminants.

Results from composting human feces in Semi-Centralized Winter Composting Unit (SC-WCU) shows that the temperatures above 55 and 65ºC were maintained for 2 weeks and more than a week respectively, which satisfies all the sanitation requirements including World Health Organization and Germany standard. In the Semi-Centralized Greenhouse Composting Unit (SC-GHCU), over 70ºC of pile temperature was achieved which meet the international standards in terms of temperature and pathogen die-off. Biological test results indicated that there was not a single Salmonella and E.coli found in the compost and the compost meet the standard of heavy metal content. The study confirmed that the greywater and human feces treatment units are technically feasible towards meeting international standards/guidelines for greywater reuse and compost products, and able to significantly contribute to develop sustainablesanitation system and to close the study area's sanitation loop in a manner that could be replicable in other parts of the world. Alternative and re-invented financial sources such as micro-finance, social capital, corporate WASH responsibility can be considered as potential sources of funding for replicating technologies and services in the study area and these can be applied in other parts of the low and middle-income regions of the world. An integration of Safe Water Supply and Sustainable Sanitation System is highly suggested to decrease the prevalence of WASH-borne diseases and to reduce the mortality rate at global level.

KEYWORDS

Sustainable sanitation, nomadic culture, greywater, composting, technology.

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ABREVIATIONS

ACF	Action Contre le Faim
GWTU	Greywater Treatment Unit
dm	Dry Matter
Eco	Ecological
GH	Green House
IB	Ice-Block
KAP	Knowledge, Attitude and Practice
l/c/d	Liter/Capital/Day
MDG	Millennium Development Goals
MNT	Mongolia Tugrik
MSUA	Mongolian State University of Agriculture
MUST	Mongolian University of Science and Technology
NGO	Non-Governmental Organization
NUM	National University of Mongolia
SC-WCU	Semi-Centralized Winter Composting Unit
SC-GHCU	Semi-Centralized Greenhouse Composting Unit
SS	Sustainable Sanitation
SSS	Sustainable Sanitation System
SWOT	Strength, Weakness, Opportunity and Threat
UB	Ulaanbataar
UDDT	Urine Diverted Dry Toilet
UNEP	United Nation Environmental Protection
UNICEF	United Nations International Children's Emergency Fund
USTB	University of Science and Technology Beijing.
VIP	Ventilated Inproved Pit latrine
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization

1 - INTRODUCTION

1.1 BACKGROUND

At present, water, sanitation, and hygiene (WASH) is a global concern and priority area in the research and international development sector [1, 2, 3]. In many of the world's undeveloped or partially-developed countries, and even in some developed ones, frequent outbreaks of various WASH- and greywater-borne diseases (e.g. schistosomiasis (bilharzia), cholera, diarrhoea, giardiasis, cryptosporidiosis, Legionnaires' disease, malaria, Ebola, various gastrointestinal and other infectious diseases are still prevalent [4, 5, 6, 7, 8, 9, 10, 11, 12, 13] . Cholera epidemics have a recorded history; for instance, in east Africa cholera epidemics have been recorded since the 1830s [14], and the existence of an unsatisfactory water supply and poor sanitation conditions in German East Africa was recognized as early as 1914 [15]. Cholera outbreaks can frequently be traced to a lack of proper household toilets and communities' heavy reliance on pit latrines and bush/ open defecation [14]. The United States has invested billions of dollars (worldwide investments are as yet undetermined) to diagnose, treat, and manage the onset, active and recovery phases of pathological conditions, without comprehensively addressing the treatment and control of pathogen sources. Treatment costs for giardiasis, cryptosporidiosis and legionnaires' alone total 978 million USD per annum, and represents only a fraction of all waterborne disease costs in the USA [4]. Proper cost estimation for undeveloped or partially-developed countries remains incomplete.

Although the Millennium Development Goals (MDGs) include improved drinking water supply, water quality and safety are still very precarious in many regions of the world. Globally, 748 million people still rely on unsafe drinking water sources such as rivers, streams, ponds, unprotected open wells, and poorly protected springs. In addition, even some populations who are using "improved" drinking water sources are not consuming safe water [16]. Improved sanitation facilities for one billion people need to be ensured by 2015, in order to meet the sanitation target set by the MDGs [3]. In 2002, WASH-related deaths and disabilities occurred globally among children 14 years old and younger at rates of 25% and 22%, respectively [17]. Poor sanitation accounts for the death of a child every 20 seconds, including the 88% of deaths caused by diarrheal disease and insufficient access to sanitation. The United Nations estimates that good hygiene and a safe water supply could save 1.5 million children a year [18].

The safety and accessibility of drinking water are major concerns worldwide. Production and consumption of water contaminated with infectious agents, toxic chemicals, and radiological hazards increase both public health and environmental health hazards, particularly in low income countries [19, 20, 21]. It has been evidenced that global incidence of WASH-borne illness, particularly cholera, has increased by 130% from 2000-2010 [3]. Oftentimes, WASH-borne illness results directly from the exclusion of the urban poor in national WASH policy, planning, and intervention processes. One of the root causes of this exclusion has been the long-standing inability of utility and city managers and their advisors to plan and implement water and sanitation systems, which respond to the realities faced by the urban poor [22]. Both surface and ground water sources can be polluted by lack of sanitation facilities, indiscriminate disposal of waste, and the lack of good governance surrounding the provision of sanitation services [23]. In many parts of the world, disparities in access to WASH solutions often stem from socioeconomic or geographic differences, such as 'urban vs. rural', 'urban vs. peri-urban', 'rich vs. poor', 'homeless vs. non-homeless' and 'majority vs. minority' [24, 16]. In both urban and peri-urban settlements, including slums, provision of sanitation services from the government is absent or altogether ignored, particularly in low- and middle-income countries [25, 16, 26]. Mongolian peri-urban areas are no exception to this kind of attitude adopted by the government.

Mongolia, a landlocked nation bordered by China and the Russian Federation, has an estimated population of approximately 3 million [27]. The country boasts the coldest capital city of the world with an annual mean temperature of -3.7° C and a harsh climate with low precipitation (approximately 200 mm/year) [28, 29]. Ulaanbaatar, the capital of Mongolia, has a population of over one million people and is experiencing an influx of migrants from rural areas resulting in many environmental, health, and socioeconomic problems. Forest fires, floods, waterborne disease, unsafe water supply, inadequate sanitation, insufficient heating, absence of suitable roads, high concentration of uranium in groundwater, wetlands and river pollution due to industrial and agricultural pollution, untreated wastewater from the city's sewage treatment plants, and heavy metal pollution in the soil (arsenic and lead) are amongst the greatest challenges faced in the capital [28, 30, 31, 32, 33].

Mongolia is, unfortunately, not "on track" to meet the sanitation targets set by the Millennium Development Goals (MDGs) [34, 35]. The country has one of the lowest rates of access to improved sanitation, and major parts of the population rely only on very poor quality water [36]. A majority of the population —particularly in the Ger areas of Mongolia (peri-urban unplanned informal settlements that surround the city)— employ unimproved and unhygienic sanitation technologies to solve sanitary problems, most notably unimproved pit latrines [37, 38]. In urban Mongolia, the coverage of piped and improved water supply is supposedly 100% (illustrating that Ger areas are not considered "urban" and highlighting the longstanding strategic issue of using Joint Monitoring Program (JMP) as a baseline for peri-urban development projects). Sanitation coverage in urban Mongolia is 64%, which is considered improved, while the remaining 36% accounts for unimproved sanitation [35].

In Mongolia, particularly in the peri-urban "Ger" areas (informal settlements) of Ulaanbaatar, most of the people are facing a range of challenges in WASH sector and still use pit latrines and soak pit in unhygienic conditions, reflected by bad public health indicators (Hepatitis A rates, diarrheal diseases) and still the annual WASH related deaths in Mongolia is 3.5%. Water in the Ger areas is mainly provided by over 550 public water kiosks where the average water consumption is 10 liter/person/day [39]. The country is one of the 60 countries in the world with limited water resources, significantly lower than the world average [40]. Additionally, both surface water, for example Tuul River, and groundwater quality is degrading due to numerous anthropogenic activities [41, 33]. It has been projected by the CSIRO-Mk2b model about the Tuul River that the water resources will decrease up to 25% by 2080 due to the climate change impact [40]. Limited capacity in water resources and their treatment, and the limited sewerage system have been identified as major constraints for increased demand in future [39]. Moreover, Mongolian water resources are under threat of climate change and rapid urbanization with over 50 percent of the population facing challenges to obtain access to clean water [40]. Surface water is being iced for over half the year during the long winter and underground water is polluted by uranium in some areas of Ulaanbaatar [33].

One of the key strategies to overcome those challenges is to develop improved and sustainable sanitation solutions which is especially crucial in urban and peri-urban context where the risks for recontamination of the resources are high and exposure of human and environmental health to chemical and biological contaminants due to the density of population, the global hydromorphic status of the area, the constraint of water access, especially in winter, the nature and practices of the resident community (new residents, nomadic culture, poverty, limited hygiene education and practices) [42, 43, 18]. Protection of existing water resources, environment and health system are also urgently required on priority basis.

This study was, therefore, carried out in the Ger (traditional felt tent) area of Ulaanbaatar, Mongolia during the period of 2012 and 2014 on various sustainable sanitation technologies such as household greywater and human feces treatment systems which may contribute towards the development of sustainable sanitation system in terms of recovery of resources/nutrients through human feces composting, greywater treatment through multiple technological options, exploring financial sources, health and environmental protection from various pathogens and chemical contaminations as well as to reduce the exposure of WASH and greywater-borne hazards/threats.

1.2 OBJECTIVES, RESEARCH CONTENT AND HIGHLIGHT

Following are the specific objectives of the study:

- To assess the technical feasibility and potentiality of different sustainable sanitation technologies such as household greywater and human feces treatment technologies through onsite experiments.
- To assess socio-cultural acceptability and replicability of the household greywater and human feces treatment technologies in the study area.
- To explore alternative financial sources for up scaling household greywater and human feces treatment technologies.
- To address strengths, weaknesses, opportunities and threats on integrating safe water supply and sustainable sanitation systems.

To achieve the objectives, this research was specifically applied following research methods and tools:

- Onsite experiments such as prototype designs, site selections, constructions and monitoring (e.g. chemical and biological analysis) of different household greywater and human feces treatment systems were set up to assess technical feasibility and potentiality in Mongolia.

- Both qualitative (e.g. key informant interview, focus group discussion) and quantitative (e.g. knowledge-attitude-practice survey, structured questionnaire survey, water quality analysis) research methods were applied to assess socio-cultural acceptability, replicability and to explore alternative financial sources for up scaling household greywater and human feces treatment technologies.
- A SWOT model was applied as a research tool to address strengths, weaknesses, opportunities and threats on integrating safe water supply and sustainable sanitation systems as well as to identify the opportunities and challenges of greywater treatment and reuse in Mongolian peri-urban context.

The implication of this study is to promote the concept and increase the awareness on sustainable sanitation technologies and services and its scaling up. It will enhance to reduce the WASH-borne risks and hazards, to recover resources/nutrients and to improve health, environment and standard of living in Ger areas in Mongolia and other parts of the world.

1.3 RESEARCH HYPOTHESIS

- Household greywater and human feces treatment technology development will contribute to the sustainable sanitation system, not as waste to dispose.
- There is an increasing need and interest in urban gardening and greenery (with/without greenhouse culture) in Ulaanbaatar, both compost products and treated greywater can be used for the city and peri-urban greening and home gardening activities.
- Risks and hazards associated with high concentrated greywater will be reduced and water can be saved.
- The scourge of Viral Hepatitis and other prevalence WASH and greywater-borne diseases that cause high mortality rate will be significantly reduced when there is less contact and exposure to human excreta and contaminated greywater by using a range of alternative technologies.
- Fecal compost products with scientifically proved will be culturally and socially accepted by the most vulnerable peri-urban population in the Ger-areas and appropriate in terms of usages the compost products, uptake food produced by the compost product.
- Fecal compost manure will be used in replacing chemical fertilizer to some extend due to its readily availability, low cost and replenish the soil lost nutrients and structures in order to reduce food scarcity.
- It might create different business options for future employments.
- Various socio-economic and health benefits will be achieved.

The overall hypothesis is that household greywater and human feces treatment technologies may contribute towards the sustainable sanitation system in terms of resources/nutrients recovery, greywater treatment and reuse, safe water supply, reduction of water borne disease, and creation of business opportunities.

2.1 WASH-BORNE HAZARDS AND EXPOSURE

Over the past few decades, 'hazards' have been addressed, defined and characterized in a wide array of fields, including climate, health, environment and disaster studies [44, 45, 46, 47, 48]. CCOHS (2009) defines a hazard as 'any source of potential damage, harm or adverse health effects on something or someone under certain conditions at work' [49]. In the context of disasters, Wisner et al. (2012) refer to 'specific natural processes and events that are potentially harmful to people and their assets and disruptive of their activities [50]. Similarly, UNISDR (2009) considers that a hazards is "a dangerous phenomenon, substance, human activity or condition that may cause the loss of life, injury, or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage" [51]. In the particular context of WASH, hazards include 'harmful substances (physical/chemical/biological) that originate from the absence/lack/failure of water, sanitation and hygiene interventions/ programs/ policies and cause loss of life, disability, other health impacts, socio-economic loss, or environmental bane' [52, 53, 54, 55, 17].

On the other hand, 'exposure' includes "people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses" [51]. Numerous pathways of exposures to both biological and chemical contaminants have been identified in freshwater and food, which may increase waterborne infections as well as fetal and infant death in many parts of the world —most notably low-income countries [56, 57, 58, 59, 60]. The exposure pathways include, for instance, air and water systems, soil, sewage, and food, among other indirect forms of contact. These studies are important; and greater efforts are needed to reduce exposure to both WASH and health hazards [61, 62]. To this end, the exposure science should be considered widely to reduce or prevent exposures to WASH-borne hazards for all groups, without any disparities.

When public health and WASH are intertwined, comprehensive WASH-borne hazard analyses can be conducted. As early as the nineteenth century, John Snow (1855) defined water as a "vehicle of disease transmission" [63]. It is indeed said that drinking water is a major source of microbial pathogens in low-income countries, while poor WASH accounts for millions of deaths every year. Lack of access to potable water, poor quality of water, absence of sanitation facilities, lack of hygiene practices, and environmental factors are all considered as possible causes of waterborne diseases due to microbiological and chemical hazards [64, 65, 55, 48]. As a result, addressing WASH-borne hazards is urgently needed to protect affected populations from various kinds of chemical and pathogenic contaminants. Figure 2.1 summarizes factors which significantly increase WASH-borne hazards. Lack of access to proper WASH facilities and lack of resources (e.g. income) likely reduce capacities to tackle WASH-borne hazards, while increasing exposure to WASH-borne hazards and threats. Alwang et al. (2001) addressed the poor and near-poor as vulnerable groups due to their inferior access to resources and limited abilities to respond to hazards [66].

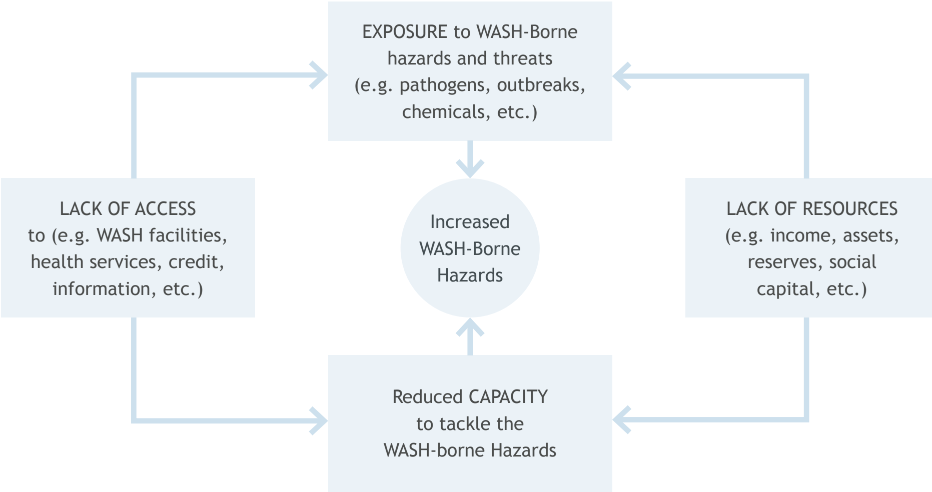


FIGURE 2-1 FACTORS LEADING TO INCREASED WASH-BORNE HAZARDS (ADAPTED FROM WISNER, 1996).

2.2 SUSTAINABLE SANITATION SYSTEM

Sustainable sanitation system (SSS) is considered as a new system for wastewater treatment that integrates non-water-borne and non-flushing toilet and enhance converting excreta to organic fertilizers/soil conditioners through composting feces, greywater treatment, recycling waste/nutrient. The major objective of the system is to protect human health and environment and reduce the use of water and recover nutrients/resources [67]. SuSanA (2008) defined sustainable sanitation system "as a system which protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable, a sanitation system has to be economically viable, socially acceptable, technically and institutionally appropriate, it should also protect the environment and the natural resources" [68, 69]. The research, development, and implementation of SSS involve several concepts, such as closed-loop-sanitation-system (CLSS), complete sanitation, ecological sanitation, environmental sanitation, and resource-reuse-oriented sanitation [20, 70, 71, 72]. SSS is a holistic system of improved sanitation techniques which enhance to recover nutrient and energy resources, reuse treated greywater, improve health conditions, and protect the environment. Improved sanitation plays a key role in ensuring public health and access to safe drinking water [73].

The study of Guzha et al. (2005) recommended that the ecological sanitation concept and the reuse of human excreta, both feces and urine, can be considered as alternative excreta management options in catchment areas which can protect the watershed from diffuse pollution to some extent [74]. Although it is possible to recover resources from the conventional systems, but it is very expensive and considered as an anti-poor technology. which is not affordable for the poor people in low income countries [75]. On the other hand, a considerable amount of nutrients can be recovered to use for agricultural production through composting and bio-gas production by using human and other organic wastes with fecal matters and urine from a simple sustainable sanitation technologies with affordable cost [76, 77].

Esrey et al. (1991) investigated the improvements in water supply and sanitation, particularly on human excreta disposal, water quality, and personal and domestic hygiene, which can reduce the occurrence of waterborne diseases [78]. Therefore, the integration of safe water supply into sustainable sanitation system and hygienic practices in both low and high income countries may reduce WASH-borne diseases such as diarrhea. Some researchers identified the collection, storage, transport and treatment of greywater and human excreta as major components of sustainable sanitation system [79, 80].

2.2.1 GREYWATER TREATMENT AND REUSE

Global water stress and scarcity, depletion and pollution in high, middle and low income countries have been addressed in many studies [81, 82]. A growing number of contaminants are entering water bodies due to anthropogenic activities [54], which may dramatically reduce the amount of potable water on earth. Greywater (the water released from domestic sources except toilet) definitions and characteristics are well documented in a range of studies [83]; treatment and reuse can be one potential option to solve the problem of reuse for different purposes which are at the source of a greater portion (the range is 50-80%) of domestic wastewater generation [84, 85]. A study by Jeppesen (1996) reveals that 30-50% water can be saved at household level, if all greywater is reused after some sort of treatment [83].

In particular, exposure to various greywater-borne diseases such as Lagionnaires (Legionella pneumophila) and various gastrointestinal and infectious diseases may increase [86, 87]. Although some argue that greywater is considered safer than blackwater (the water released only from toilets), it has been shown in the literature that greywater can cause risk and hazards to various human organs as well as to the environment (e.g. soils, plants, useful organisms/decomposers, surface and groundwater) as a result of both chemical contaminants and transmission of hazardous microbes and pathogens [88, 89, 90, 91, 92]. In addition to common chemicals and biological agents assessed in the greywater, it has been identified that 900 types of xenobiotic organic compounds (XOC) can also be found in greywater which can accumulate in soil and groundwater leading to human, agricultural and environmental health hazards [88]. Additionally, fecal contamination can be transmitted through greywater through a range of medium including laundry, childcare (e.g. diapers), showers, food-handling in the kitchen, and the sink basin. In these cases, viruses or bacteria such as Pseudomonas aeruginosa can thrive on easily degradable organic matter [93, 92].

During the past decades greywater has dramatically gained attention for treatment and reuse in countries with different climatic patterns including cold regions in order to tackle the shortage of water, minimize health hazards, conserve the environment and reduce environmental risks [83, 94, 95]. There might be various challenges to treat and reuse greywater in various climatic zones [82].

To fulfill the global water demand and to secure and ensure a safe water supply, a range of alternatives are needed to treat and reuse recyclable water in terms of numerous factors such as economic viability, technological suitability and adaptability, socio-cultural acceptability, political stability and institutional capability.

Table 2.1 shows the potential technological options for treating greywater and reuse.

TABLE 2.1 BRIEF HIGHLIGHTS OF DIFFERENT GREYWATER/WASTEWATER TREATMENT TECHNOLOGIES.

TYPE	DESCRIPTION
MBBR (Moving Bed Biofilm Reactor) [96]	The MBBR process is based on the aerobic biofilm principle and utilizes the advantages of activated sludge and other biofilm systems without being restrained by their disadvantages.
	It has high efficiency and effectiveness in biological wastewater treatment process to remove pollutants.
MBR Process [97]	The MBR combines an activated sludge reactor with a membrane filtration unit to treat wastewater.
	It does not require large land/space to setup.
Biological Aerated or Anoxic Filter Process (BAF) [98]	Biological Aerated (or Anoxic) Filter (BAF) or Bio filter combines filtration with biological carbon reduction, nitrification or de-nitrification. BAF usually includes a reactor filled with a filter media.
	It is considered as effective and flexible bioreactor with small footprint which has potentiality to remove high organic content from wastewater stream.
Constructed Wetland (CW) [99]	A constructed wetland system (CW) pretreats municipal/domestic/industrial wastewater by the processes of settling, filtration, and bacterial decomposition in a natural-looking lined marsh.
	Constructed wetland systems have been used over 50 years at global level with high potentiality and efficiency in removing both chemical and biological contaminants.
	However, the performance may decrease during the cold climatic conditions.
Septic tank + BAF + ABF (Aerobic Biofilm Filter) [100, 101]	This is a combined system. This system is composed of septic tank, Baffled Anaerobic Reactor Aerobic Biofilm Filter.
Willow Wastewater Treatment system [102]	Willow wastewater treatment plants are considered as low technical process and high biological activities.
	The plants are high resilient to polluting substances in wastewater.
4-in-1 system [103]	In this system, a biogas digester, a greenhouse, a pigpen and a toilet are integrated in order to use the wastewater and waste to produce biogas, fertilizer, and to realize zero discharge.
Anaerobic Baffled Reactor (ABR) [101]	An Anaerobic Baffled Reactor (ABR) is an improved septic tank.
	It can be considered a series of up-flow anaerobic sludge bed (UASB) reactors that can play significant role in the field of wastewater treatment.
Anaerobic Filter [104]	An Anaerobic Filter is effective for the treatment of wastewater with low organic content.
	However, recycling and settling of organic solids are required to increase the efficiency of the treatment process.
Waste Stabilization Ponds (WSP) [105]	Waste Stabilization Ponds (WSPs) are considered as easiest operation and maintenance, efficient treatment and economically feasible technology.
Horizontal Subsurface Flow Constructed Wetlands [106]	It is an effective, economically and technically feasible for wastewater treatment.
	It consists of gravel and sands with planted aquatic plants for the treatment purposes with the help of microorganisms.
Vertical Flow Constructed Wetland [107]	It is an excellent technique to remove nutrients and certain pollutants from wastewater.
Upflow Anaerobic Sludge Blanket Reactor (UASB) [108]	It is versatile and flexible technology with low cost operation and maintenance.
	This kind of reactors have been applied to treat a range of industrial effluents such as slaughterhouse, food processing, piggery, and manure.
Sedimentation / Thickening Ponds [109]	These technologies serve as primary treatment process by providing sufficient residence time and can remove specific nutrients (e.g. phosphorus) through a range of mechanisms.
Anaerobic Biogas Reactor [110]	It can be considered as a treatment technology and can produce biogas for energy.

2.2.2 HUMAN FECES TREATMENT: COMPOSTING AND CO-COMPOSTING

Composting, one of the oldest bio-technological processes of organic waste treatment including human feces, is considered as one of the sustainable sanitation solutions. It has long been considered an important tool in organic gardening and farming, as well as a valuable waste management technique [111]. A written reference to composting and its use in agriculture appears in documents from the period of the Akkadian Empire (2300 B.C.E.) [112]. As a biological waste treatment process [113], composting is applied in stabilizing and sanitizing sewage sludge (Dumontel et al., 1999) [114]. A wide range of research has been conducted during the 20th century that confirms the usefulness of compost in improving the production of horticultural crops [115].

Composting is defined as the controlled biological decomposition and stabilization of organic substrates under a set of factors (e.g., temperature, moisture content, carbon to nitrogen ratio, degree of aeration, pH level, and physical structure of the raw material) which allow for development of thermophilic conditions as a result of biologically-produced heat. The final product should be stable, free of pathogens and plant seeds, and beneficial when applied to land as bio-fertilizer [116, 117, 118]. Referring to biodegradable waste, composting is considered more advantageous than landfilling and incineration due to its lower investment and operation costs, lower environmental pollution, and beneficial use of the end-product [119]. Of course energy recovery from composting is unusual [120] as the released heat is internally used to accelerate the process.

The composting process destroys pathogens, converts nitrogen from unstable ammonia to stable organic forms, reduces the mass, volume and water content, and also improves the nature of the waste [121, 122, 123]. In addition, it is not only an 'approach' to handling organic waste in an environment friendly manner, but also a way to recover resources and nutrients for sustainable development [124, 119]. Different varieties of organic degradable materials such as household and municipal wastes, animal manure and human fæces, food processing wastes, paper and pulp waste, agriculture wastes, sewage sludge, poultry litter, and aquatic plants [125, 126, 127, 128, 124, 129, 130], can be used in the composting process through the use of suitable techniques such as windrow, in-vessel, static pile, and vermi-composting [131, 132]. The main objectives of composting are to stabilize the biodegradable organic matter in raw wastes, to reduce offensive odors, to kill weed seeds and pathogenic organisms, and to produce a fertilizer suitable for wide distribution and land application.

Co-composting is a controlled aerobic degradation of more than one organic material, such that by the combination of materials (e.g., fæcal sludge and organic solid waste, human fæces and straw, aquatic plants and sawdust) benefits can be gained in terms of process optimization. Human excreta is high in nitrogen content and moisture, while garbage is high in organic (carbon) content and has good bulking qualities; therefore these can be converted together into a useful product [133]. Co-composting of sewage sludge with fly ash can significantly reduce the availability of heavy metals in the composted sludge [134]. Wastes can be categorized according to their five main sources [125, 126, 127, 128, 124, 129]:

- animal and human (e.g., cow-dung, poultry litter, pig and horse dung, human fæces),
- agricultural (e.g., straw, agro-residues),
- household, municipal or industrial (e.g., food waste, market waste, kitchen waste, pulp and paper mill waste),
- aquatic and other plants (e.g., Hydrilla [Hydrilla verticillata (L.f.) Royle], water hyacinth [Eichhornia crassipes (Mart.) Solms], and tobacco [Nicotiana tabacum L.] waste, and
- yard trimming and other organic detritus (e.g., grass clippings, herbs, shrubs, leaves wood-chips)

The composting process is an exothermic reaction that involves several microorganisms that cause decomposition under natural yet controlled environments. Under the thermogenic conditions, the process destroys pathogens, converts N from unstable ammonia to stable organic forms, reduces the volume of waste, and improves the nature of the waste [135]. The process can be expressed by the following equation [132] and the input and output of composting process can be explained in the Figure 2-2:

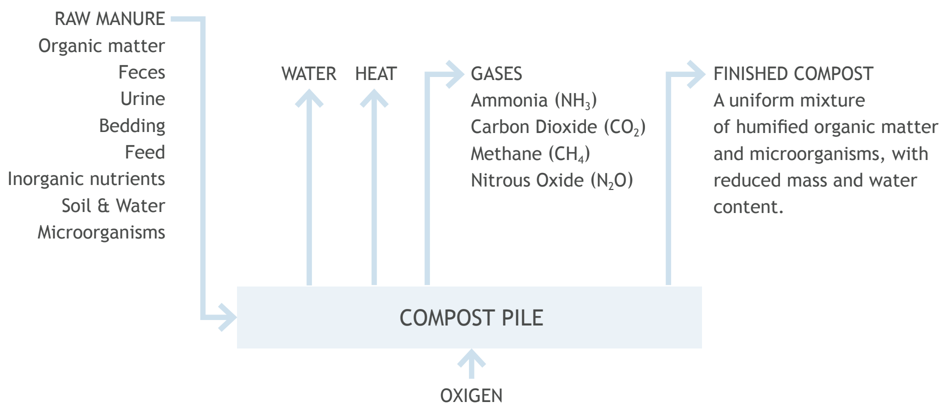


FIGURE 2-2 INPUT-OUTPUT OF COMPOSTING PROCESS.
(SOURCE [125, 132])

The product of composting is considered a potential source of bio-fertilizer, and is either harvested from composting toilets or transferred from composting toilets to vermicomposting systems [136].

POTENTIAL TECHNOLOGIES FOR HUMAN FECES COMPOSTING

A wide range of traditional and advanced composting technologies can be found in different geographical and climatic zones depending on their appropriateness, efficiency, and economic feasibility [133, 137, 138]. As outlined below, in terms of pathogen reduction or destruction, human health and environment protection, and recovery of resources/nutrients, the main potential composting technologies include: vermicomposting, compost Toilets/Bio-Toilets/Eco-Toilets/UDDTs, Static Pile/Bin/Box, Closed-Pit and Windrow Composting.

Vermicomposting

Vermicomposting is an accelerated process of bio-oxidation and stabilization of organic wastes that involves interactions between earthworms and microorganisms. It took nearly 100 years after Darwin's 1881 study and description of the role of earthworms in the decomposition of organic matter for the concept of vermicomposting to be viewed as a viable technology [139]. Of the roughly 7250 species of earthworms so far discovered, over 3600 exist in terrestrial environments. While a number of these have been tested in the field of vermicomposting of organic wastes [140], few have been applied in composting processes for human fæces/sludge [141, 142]. As vermicomposting has been found to completely inactivate total coliforms during the composting process, it was deemed as a technology of high potential for treating source-separated human fæces [143]. Vermicomposting has also proved to be a realistic and practical solution for the treatment of sewage sludge [144]. A combination of traditional thermophilic composting and vermicomposting techniques may both shorten the stabilization time and improve the quality of the products. In addition to generating a more stable and homogenous product, this technology could meet requirements of pathogen reduction [145]. Tognetti et al. (2008) showed that the combined effect of earthworm activity and a shorter thermogenic phase during the vermicomposting of municipal organic wastes led to the highest concentration in organic matter, Total Nitrogen (TN), and nutrient availability [146]. Use of this technology to renew and improve soil fertility would be widely acceptable in many countries, particularly in African regions where major nutrient (e.g., Phosphorus and Nitrogen) deficiencies exist [147]. Sierra et al. (2013) showed that vermicomposting can be considered for tropical environments, and that it is favorable to the stabilization of organic matter [148]. Ansari (2009) concluded that vermicomposting in the organic waste management field could facilitate the transition towards zero-waste production and recycling-based societies [149].

Interest and research into vermicomposting in China has grown significantly since the early 1990s. For example, in a study by Feng (2008) [150], the optimum temperature was controlled at 20°C, moisture content at 55%-60%, and this generated compost with between 40% and 60% organic matter. The results showed that vermicomposting reduced the total nitrogen content of sludge, enhanced the effective nitrogen content, and at the same time improved the total phosphorus and effective phosphorus content. After application of the vermi-compost, the plant height, and yield of Chinese cabbage was significantly increased. Zhou et al. (2011) [151] showed that the thickness of the feed additive, as well as the particle size and degree of maturity of the raw material greatly influences vermicomposting: a feed layer thickness of 0.15 m led to the greatest earthworm weight gain, whereas a greater thickness led to the death of some worms, presumably as a result of the inability for sufficient oxygen to diffuse into the material. Conversely, as earthworms prefer living in the dark, the thickness of the feed layer cannot be too thin. Since earthworms have no teeth, they cannot breakup and ingest large particles. A particle size of 5-10 mm was found to enhance earthworm quality, but much smaller particles sizes adversely affected worm growth by affecting ventilation conditions. In addition, the vermicomposting of rotten fresh water hyacinth performed significantly better than that of fresh water hyacinth. In a study conducted by Yuan (2012) [152], the TN, TP and TK, alkali solution nitrogen, effective phosphorus and effective potassium generated through vermicomposting were significantly greater than those of the control group of aerobic composting without earthworms. The vermicompost generated a product with a C/N ratio of 8.7±1.3 and a GI of over 85%. The non-hazardous nature of the material was noted: pathogen and heavy metal content were in accordance with Chinese control standards for landscaping and land reclamation. The study also showed that well-characteristics of vermicompost (e.g high porosity, loose structure and abundant granule structure) can be achieved from the sewage sludge through vermicomposting process which can be harmless and considered as valuable resources. Hill (2012) [153] showed various benefits from the source separation of vermicomposting toilets and showed that the system's pathogen reduction mechanism results in low *E. coli* numbers in the products, low operational hazards, and reduced fæcal contamination in leachate.

Compost toilets/bio-toilets/eco-toilets/UDDTs

The invention of the compost toilet or bio-toilet was driven by the aim to protect human health and the environment in general. While first invented and patented in the 1860s, the compost toilet was re-invented and commercialized some four decades ago, and are thus a fairly recent development in the fields of water, sanitation, health, and agricultural. The Chinese and Vietnamese are pioneers of modern composting toilets. Old and modern composting toilets appeared in Norway and Sweden in the 1940s and 1970s, respectively [154, 155, 156], and brought growing attention to this technology in many parts of the world, including Europe [157]. After some modifications, including proper insulation of the compost toilets, the outputs in the laboratory were achieved at the field level [158]. Composting toilets and their history, design, suitability, advantages, disadvantages and potentiality have been widely discussed [159, 160, 161, 156, 162]. Given their potential to prevent adverse health consequences stemming from unsanitary and unhygienic conditions, and to contribute to agroforestry by using compost and urine to enhance food production and tree growth, it is important that an effort be made to promote the inclusion of compost toilets in households that are inexpensive, as well as easy to construct, use and upgrade [162]. The reduction of pathogens from human fæces to harmless levels is possible through primary or secondary treatment (through composting) of either on- or off-site [156].

After flushing, existing toilet waste from cities and towns flows through pipes into either sewage treatment plants or directly into rivers and lakes. Wastewater treatment requires significant expenditures, and a great deal of the natural fertilization resource waste waters represent, as well as the water itself, is often wasted. With rising urbanization, this situation is steadily worsening. At present, two main types of environmentally safe toilets exist: water-free (i.e., composting) and circulating water flush toilets [163, 164]. The former generate little or no wastewater, do not require a sewer system, and generate a product that can serve as an environmentally safe organic fertilizer. At present, in China, various types of bio-toilets are seeing practical application and the technology have gradually matured. However, packaging type and recycling flush toilets are more widely used, particularly in public places, scenic spots, and at sites of temporary gatherings [165]. Bio-toilets are also used in Japan in public places such as sightseeing places, parks, and households [166]. Proper self-heating condition and biological diversity can be obtained by using single/double-vault toilets to kill the pathogen and to achieve safe compost products [161]. Using double vault composting latrines in Vietnam, Jensen et al. (2009) [167] showed that over 99% of Ascaris suum eggs could be inactivated though the composting process and acceptably sanitized fertilizers could be obtained over the three month storage period. Composting toilets are also known as waterless biological toilets which has suitable and waterless environment to produce harmless residue from human excreta [159]. Waterless and solar composting toilets were installed in the Colorado Park towards decomposing wastes to avoid water and chemical usage as well as to control pollution and odor. The compost products from those toilets were similar to topsoil where significant reduction of the volume was achieved [154]. A condition of a bio-toilet for sanitary disposal of human fæces was simulated at laboratory scale and the results shown that over 70% removal rate of organic matter can be achieved without P and N loss to the environment which can control polluting lake, wetlands and other surface water bodies [168]. A bio-toilet (S-50 type) of Japan was constructed and characterized the composted residue by Triastuti et al. (2009) [169] and shown that the product is suitable as soil conditioner because of its high porosity, low bulk density, high water retention, and neutral pH. It also increased the leaf number, leaf area, stem height and stem diameter of Jatropha curcas. Kakezawa et al. (1992) [126] has conducted a two-step composting process of activated sewage sludge with the raw rice straw in a laboratory scale and displayed a good quality of compost with 100% germination rate of Komatsuna seeds.

The Urine Diversion Dry Toilet (UDDT), a type of eco-toilet which has become popular in recent years, has shown potential for use as an sustainable/ecological/environmental sanitation tool in both low and high income countries [170]. Usable at sites with little or no infrastructure as well as in vehicles (e.g., trains), these water-conserving toilets save and protect water resources and through their zero-pollution, zero-discharge and zero-infection design are particularly environmentally-friendly. They reduce the volume of waste while offering the potential for resource recycling towards agro-production, with its associated economic and environmental conservation benefits [165, 171, 172, 163, 173, 174]. The principle of the UDDT is to separate human urine and fæces, and stockpile them in different storage systems. The urine is collected and drained from the front portion of the toilet while fæces fall into a protected chamber. Locally available materials such as wood ash, dry soil, sawdust or other liming materials are sprinkled on the fæces after they reach the chamber to help to dry up the fæces rapidly. This allows their conversion to bio-fertilizers within six months, and ensures the destruction of pathogens [175].

UDDTs are an important composting technology, and are frequently used for the onsite treatment of human fæces [176, 69]. Liu et al. (2008) showed that organic fertilizers derived from bio-toilets are effective in producing greater and steadier corn (Zea mays L.) yields than inorganic fertilizers. They suggested that applying this technology could not only solve non-point source pollution issues, reduce the use of inorganic fertilizers, but also increase the yield and quality of corn [173]. Gong et al. (2009) have also shown that clean, dry biological fertilizers can be produced by bio-toilets. Additionally, such toilets significantly improved local pollution issues through their significant reduction of water wastage. They concluded that significant energy and resource conservation, along with environmental protection, can be achieved by using UDDTs [177]. In regions where temperatures are favorable to the composting process, UDDTs can be considered for onsite composting systems, while under colder climates they may supply the raw materials for centralized off-site composting systems.

Static pile composting

Using forced ventilation static pile system to compost dewatered sludge, Lv (2007) [178] showed that mixing dewatered sludge, fly ash and sawdust together made the warming attendant upon the composting process proceed smoothly. Under these conditions, elevated temperatures of 50°C to 55°C could be reached and maintained for 5 to 7 days. In addition, the products of composting met relevant standards of compost application. An experiment with an orthogonal design showed a ratio of dewatered sludge: fly ash: sawdust to be 78:20:2, a moisture content of 72%, and a ventilation rate of 120 m3 h-1 to be optimal. Cai et al. (2012) [179], have shown that pile composting of sewage sludge with manual turning has a potentiality to reduce organic contaminants such as polycyclic aromatic hydrocarbons and phthalic acid esters up to 58.3% and 90.6% respectively.

Batch-dynamic composting

Recent years there has been a new development of static composting system which is batch-dynamic composting system. It is the combined system of static and dynamic compost treatment. The major features of this system are short fermentation cycle, simple processes, minimum number of fermentation tanks and low investment costs. An environmental protection enterprise operates 80 wastewater, solid kitchen waste, and fæcal matter treatment plants across the country. Currently, three of China's six large-scale batch-dynamic composting plants operate in Beijing. The Changping composting plant in Beijing formerly had a capacity of 200 Mg d^{-1} (2003), with its capacity expanding to 300 Mg d^{-1} in 2005. It daily collects fæcal sludge from the septic tanks of Beijing households (50 Mg d^{-1} of kitchen waste). After dewatering, the sludge [18% total solids (TS)] was mixed with organic additives such as rice husks and sawdust, and the thickened material composted to yield a compost meeting a 30-40% TS end product quality requirement. Roughly 5-6 Mg of compost can be derived from 100 Mg of input materials (i.e., 24 Mg d^{-1} are produced from the input of 300 Mg d^{-1}). Outflowing liquid was channelled to a nearby waste water treatment plant with a processing capacity of 80 Gg d^{-1}. (CGEET, 2014, Personal communication during field visit). Requirements for effective compost production are 6 days with a temperature at the centre exceeding 50ºC, and natural self-heating, the only additional heating to prevent frosting of equipment in winter time. The plant is fully subsidized by the Chinese Government and does not sell compost to the public. Compost utilization is for governmental purpose only, and mainly used for city landscape greening due to the small scale of production. The quality of the compost and the condition of the equipment used in its production is monitored monthly by the Chinese Ministry of the Environment, and must meet GB 8172-87 Control Standards for urban wastes intended for agriculture use (www.nthb.cn). The plant's installation cost was 20 million RMB/ 3.27 USD. The plant receives government subsidies of 56 RMB/ 9 USD Mg-1 of material treated, allowing the operation to keep running year round. Table 2.2 shows the regular monitoring test results of the Changping composting plant in Beijing.

TABLE 2.2 COMPOST QUALITY STANRD AND MEASURED VALUES FOR THE CHANGPING COMPOSTING PLANT, BEIJING, CHINA

QUALITY PARAMETER	UNIT	STANDARD	TEST RESULT
pH	-	6.5-8.5	7.85
Cd	mg kg^{-1}	≤ 3	0.617
Total As	mg kg^{-1}	≤ 30	10.553
Total Cr	mg kg^{-1}	≤ 300	116
Total Hg	mg kg^{-1}	≤ 5	0.907
Water Content	%	25-35	7.33

QUALITY PARAMETER	UNIT	STANDARD	TEST RESULT
Pb	mg kg-1	≤ 100	6.22
TN	%	≥ 0.5	1.13
TK	%	≥ 1.0	0.876
TP	%	≥ 0.3	1.13
Volumetric Weight	kg m-3	-	388
Total Organic Matter	mg kg-1	-	42.67
Fecal Escherichia coli	No. kg-1	-	> 9000
Roundworm egg mortality	%	95-100	Not detected

(SOURCE: FROM THE FIELD OFFICE OF CGEET, JANUARY 2014)

The biological test restutls of compost shown that majority of the heavy metal (e.g. Cd, As, Cr, Hg) concentration incldiung pH, TN, TP meet the Chinese standard for agricultural application.

Bench-scale composting, closed-pit and Bin/Box Composting

A bench-scale composting bioreactor was constructed by Zhou et al. (2014) [180] and recyclable plastic bulking agent (RPBA) was used for composting sewage sludge and the results of the germination index of the product was found to be phytotoxic free. The RPBA has been used also to reduce the costs associated with the composting processes. Vining (2002) [181] shown that low priced equipment can be used to obtain the self-heating bench-scale composting system. A simple modification of the reactors can accelerate the complete breakdown of the materials composted. A bench-scale bioreactor was experimented in the study conducted by Potter et al. (1999) [182] and shown that higher biomass can be obtained by using the activated sludge in the system than the cow-dung.

A closed-pit composting method is feasible under tropical conditions, as temperatures in such countries are favorable to the elimination of pathogenic microorganisms [183]. Tognetti et al. (2008) carried out a traditional static pile composting of organic wastes under tropical conditions, and found that N and P availability and nutritional capacity increased in soils amended with the composted products. Co-composting of municipal organic waste with bio-solids was considered to be more effective in terms of product degradability and nutrient release capacity [146].

A static bin system was used by Preneta et al. (2013) [184] for the thermophilic (>65°C) co-composting of human fæces in Haiti over a period of over one month. Rapid pathogen die-off rates were noted within the compost pile, such that the number of *E. coli* dropped below detection levels within 14 weeks [184]. Niwagaba et al. (2009) [185] suggested, even under tropical conditions, insulating the reactor (e.g., box composting) to thermally sanitize the compost products. A sanitinsing temperature (≥ 50°C) was maintained during the experiment and no *E. coli* and Enterococcus spp. were found in the samples from the system. A family size box composting unit was proposed to treat the fæces from source-separated toilets in both rural and urban Uganda.

Windrow Composting

In Argentina, outdoor turning windrow systems have been used to compost biosolids obtained from sewage treatment plants, with the location of such composting facilities chosen to minimize the attraction of flies, and the preparation of sites being based on the consideration of sanitary precautions before the preparation [186]. In China, Li (2004) [187] implemented windrow composting of chicken manure and corn straw, such that compost moisture content was controlled at about 50% and artificial rotary ventilation was adopted. His study showed that high compost temperatures (55°C to 60°C) could be maintained for about 20 days, thus achieving the temperature requirements to render the compost harmless. In the composting process, the interaction of temperature, oxygen concentration and moisture are constrained, so that adjusting these three parameters to an optimal level can significantly accelerate the composting process and improve the quality of the compost. In Ghana, Cofie et al. (2009) investigated co-composting fecal sludge and organic waste by using windrow composting system and recommended turning frequency of 10 days to save labor cost and to obtain safe compost with high nutrient content [188].

PATHOGEN REDUCTION, HYGIENIZATION AND HEALTH ISSUES

The improper management and lack of proper monitoring of windrow technology systems can result in a number of pathogens being found in compost produced by such systems. Open-air windrow systems employed in organic composting should be controlled to reduce their exposure of dust, bacteria, fungi, actinomycetes, endotoxins, which may cause respiratory and dermal illnesses (Giusti, 2009) [189]. Although conversion of human excreta to a fertilizer is a challenge, the composting of human fæces with appropriate technology, the consideration of important production factors (e.g., temperature, moisture content), and precautions being taken during the process can protect from any serious infections and allow for the recovery of nutrients in a hygienic manner [190, 143]. Pathogens and parasites, and the WASH-borne diseases they cause (Table 2.3), are generally killed by the elevated temperature which occurs during the composting process (Table 2.4).

Most of the viruses are killed within 25 minutes at 70°C, whereas the survival of bacteria varies from time to time and place to place [191]. The compost can generally be sanitized when the temperature is maintained over 55°C for 3 days during the composting process [192]. Redlinger et al. (2001) recommended to use compost product from the compost toilets when it is matured after 6 months to the edible plants or in the places where people could be exposed either direct contact or through dust flow [193].

TABLE 2.3 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER.

ORGANISM	DISEASE CAUSED
BACTERIA	
Escherichia coli (Migula 1895) Castellani and Chalmers 1919	Gastroenteritis (enterotoxigenic)
Leptospira spp. Noguchi 1917 emend. Faine and Stallman 1982	Leptospirosis
Salmonella typhi (Schroeter 1886) Warren and Scott 1930	Typhoid fever
Salmonella spp. Lignieres 1900	Salmonellosis (= 2,100 serotypes)
Shigella spp. Castellani and Chalmers 1919	Shigellosis (bacillary dysentery)
Vibrio cholera Pacini 1854	Cholera
PROTOZOA	
Balantidium coli Malmsten, 1857	Balantidiasis
Cryptosporidium parvum Tyzzer, 1907	Cryptosporidiosis
Entamoeba histolytica Schaudinn, 1903	Amoebiosis (amoebic dysentery)
Giardia lamblia (Lambl, 1859) Kofoid & Christiansen, 1915	Giardiasis
HELMINTHS	
Ascaris lumbricoides Linnaeus, 1758	Ascariasis
Taenia Solium Linnaeus, 1758	Taeniasis
Trichuris trichiura Linnaeus, 1771	Trichuriasis
VIRUSES	
Enteroviruses (72 types. e,g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

(SOURCE: USEPA, 1999 [154])

TABLE 2.4 THERMAL DEATH POINTS FOR SOME COMMON PATHOGENS AND PARASITES.

	50⁰C	55⁰C	60⁰C
Salmonella typhosa (Zopf) White	-	30	20
Salmonella spp. Lignieres 1900	-	60	15-20
Shigella spp. Castellani and Chalmers 1919	-	60	-
Escherichia coli (Migula 1895) Castellani and Chalmers 1919	-	60	15-20
Streptococcus pyogens Rosenbach 1884	-	10	-
Mycobacterium diptherae (Kruse, 1886) Krasil'nikov, 1941	-	45	-
Brucella abortus (Schmidt 1901) Meyer and Shaw 1920 **or** *Brucella suis* Huddleson 1929	-	60	3
Endamoeba histolytica Schaudinn, 1903 (cysts)	-	1/60	-
Trichinella spiralis Owen, 1835	-	-	1/60
Necator americanus Stiles, 1902	50	-	-
Ascaris lumbricoides Linnaeus, 1758 (ova)	-	60	-

(SOURCE [191])

2.2.3 FINANCIAL SOURCES FOR SUSTAINABLE SANITATION SYSTEM

The majority of projects in the field of water and conventional sanitation around the world receive funding from external sources from various donors and development agencies [194]. The rate of project failure in the water and sanitation sector are high due to a range of factors such as lack of local participation in components of the projects and appropriate investment [195, 196] from local to national levels. It has been suggested to implement policies such as cost recovery to meet Millennium Development Goals (MDGs) and to allow for clean water and sanitation [197]. Financial factors should be considered by governments to improve sanitary conditions, and to promote supply and maintenance of sanitation facilities and services [198].

Despite socio-cultural and geographical factors, one of the major challenges for up scaling technologies (e.g. eco-toilets/UDDTs) and services (e.g. emptying, collection, transportation, treatment) for SSS in low and middle income regions around the world is the potential sources of finance to build new infrastructures and to maintain the existing ones. A range of factors such as high construction costs, dependency of external funding, lack of political willingness to large scale investment, lack of proper cost-benefit analysis are other common obstacles for widespread replication of the SSS technologies and services in many parts of the world [69, 199]. To overcome those challenges, potential alternative sources of finances should be explored for widespread replication of SSS technologies and services from local to global scale.

3.1 STUDY LOCATION

This study was conducted in the peri-urban Ger areas of Ulaanbaatar (Figure 3-1, 3-2, 3-3 & 3-4) Mongolia during the period of 2012 and 2014. This informal settlement houses 60% of the Ulaanbaatar population, which continues to increase every year [38]. The Ger district named Songinokhairkhan was selected for the field experiments of the study.

FIGURE 3-1 MAP OF MONGOLIA.

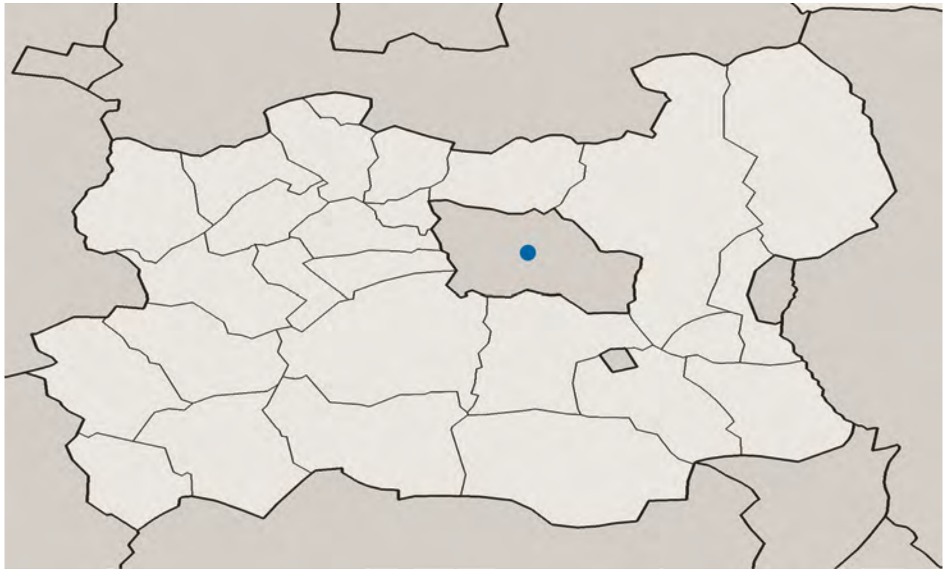


FIGURE 3-2 MAP OF ULAANBAATAR IN TOV PROVINCE.

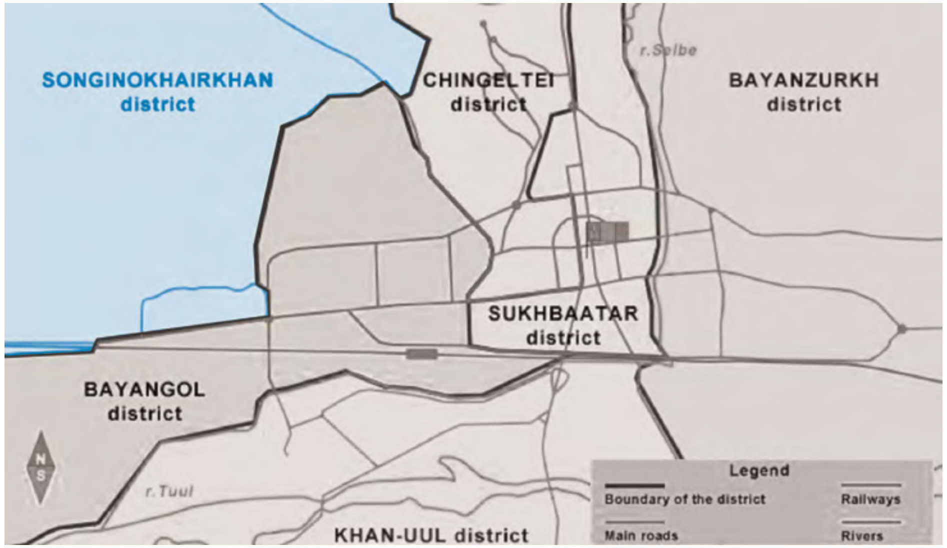


FIGURE 3-3 MAP OF CITY AND SONGINOKHAIRKHAN DISTRICT

Songinokhairkhan district was established in 1994 and consists 1200.6 km^2, and it is subdivided into 32 administrative units-subdistrict/khoroos. By January 2013 there were 261,917 population. The district has big production industries and companies of wheat flour, bread, meat and milk products. Their products are supplied to this district and other parts of the country. The main economic sectors are production of milk and dairy products, meat and meat products, pig and chicken farming and greenhouse farming enterprises. Majority of the people (around 93%) collect water from water kiosks [200, 201].

FIGURE 3-4 GER HOUSE IN THE GER AREAS OF PERI-URBAN ULAANBAATAR.

3.2 RESEARCH ROADMAP

Feasibility and replicability of a range of sustainable sanitation technologies (e.g. Urine diverting toilets, composting human feces through semi-contained, greenhouse, household greywater treatment through greenhouse and ice-block treatment units) and services (e.g. emptying services) were assessed in terms of technological, social, financial and climatic factors. Figure 3-5 shows the overall flow of the experiment of the study.

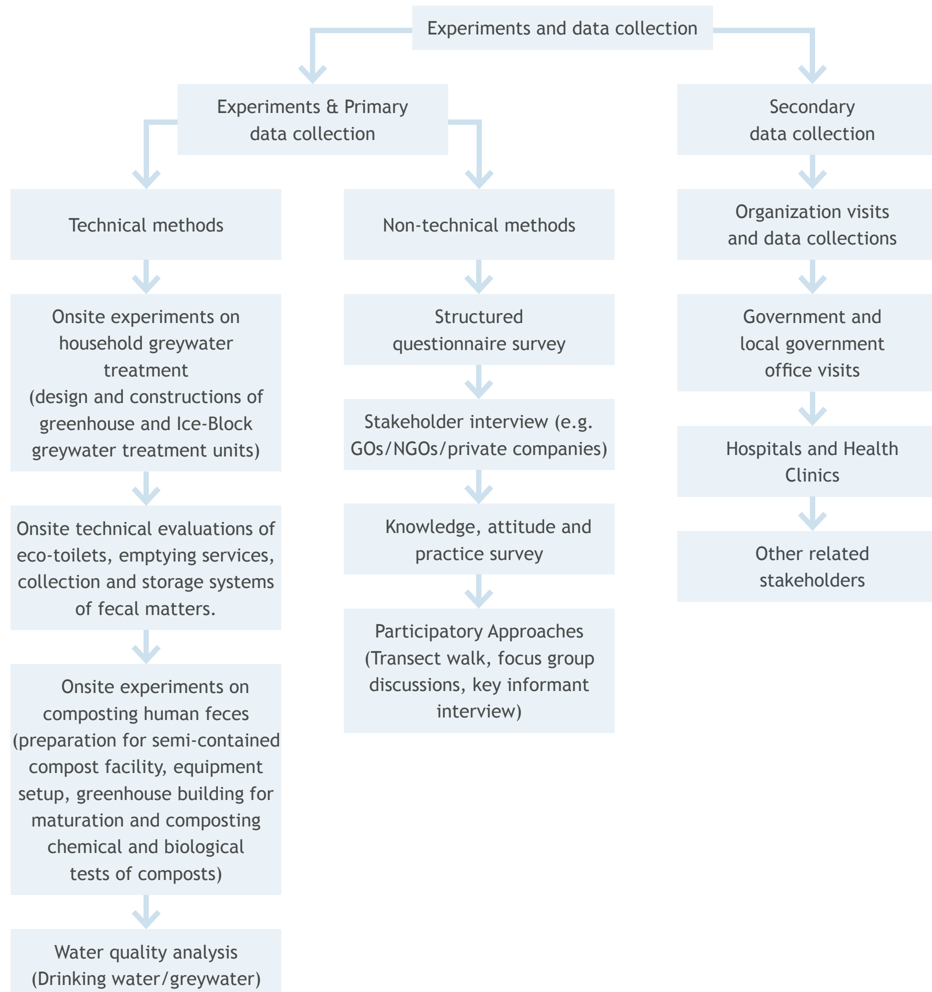


FIGURE 3-5 FLOW DIGRAM OF RESEARCH ROADMAP.

3.3 ONSITE EXPERIMENTS ON HOUSEHOLD GREYWATER TREATMENT SYSTEMS

In this study, two different prototypes have been designed, constructed and tested for greywater treatment at the selected households in the study area. Thirteen sites had been evaluated as potential sites for the installation of model greywater treatment units (GWTU) based on several criteria —for instance availability of space, people's interests, technological suitability and opportunity to reuse the treated greywater on or nearby the compound. Some households were already participating in the WASH programs of ACF Mongolia. Other sites have been visited on request of the owners by contacting ACF staff during an information session in the community. In addition, most suitable compounds were selected from those sites to pilot two greywater treatment units. The following criteria were applied for "scouting" potential GWTU sites for onsite greywater treatment: (1) activities that require water usage thus providing opportunities for reuse of treated greywater; (2) compounds with a number of trees, already installed greenhouses and/ or gardens. While on-site treatment of greywater generates a reasonable amount of water for reuse, off-site treatment of greywater —based on the collected amount of greywater from several households— requires large-scale reuse opportunities such as in tree nurseries, on agriculture farms.

3.3.1 EXPERIMENTS ON GREENHOUSE GREYWATER TREATMENT UNIT

EXPERIMENTAL SETUP

A greenhouse greywater treatment unit (GH-GWTU) (Figure 3-6 & Figure 3-7) was designed and constructed based on several factors such as availability of land, climatic condition, geographical location, per capita greywater production, and characteristics of greywater in the study area.

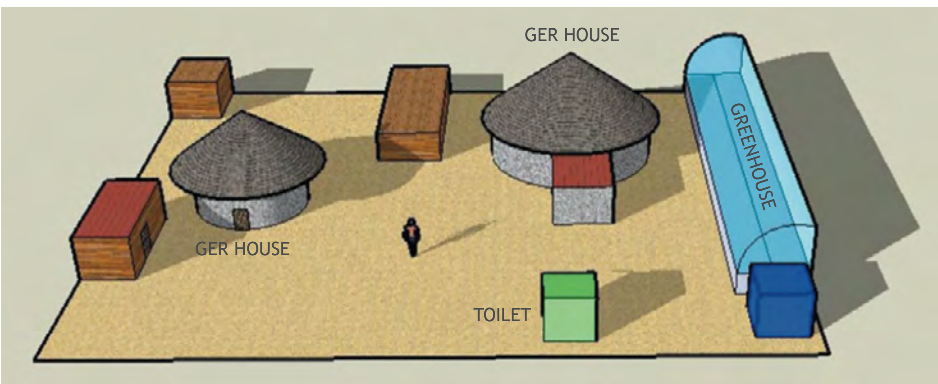


FIGURE 3-6 SCHEMATIC DIAGRAM OF A GER COMPOUND AND THE LOCATION OF GH-GWTU.

The major components of the system includes two grease traps (Figure 3-10), two septic tanks (Figure 3-11), three anaerobic gravel filters (Figure 3-12), one slow sand filter (Figure 3-13) and an effluent tank. Figure 3-9 shows the design of greenhouse which was used for this greywater system.

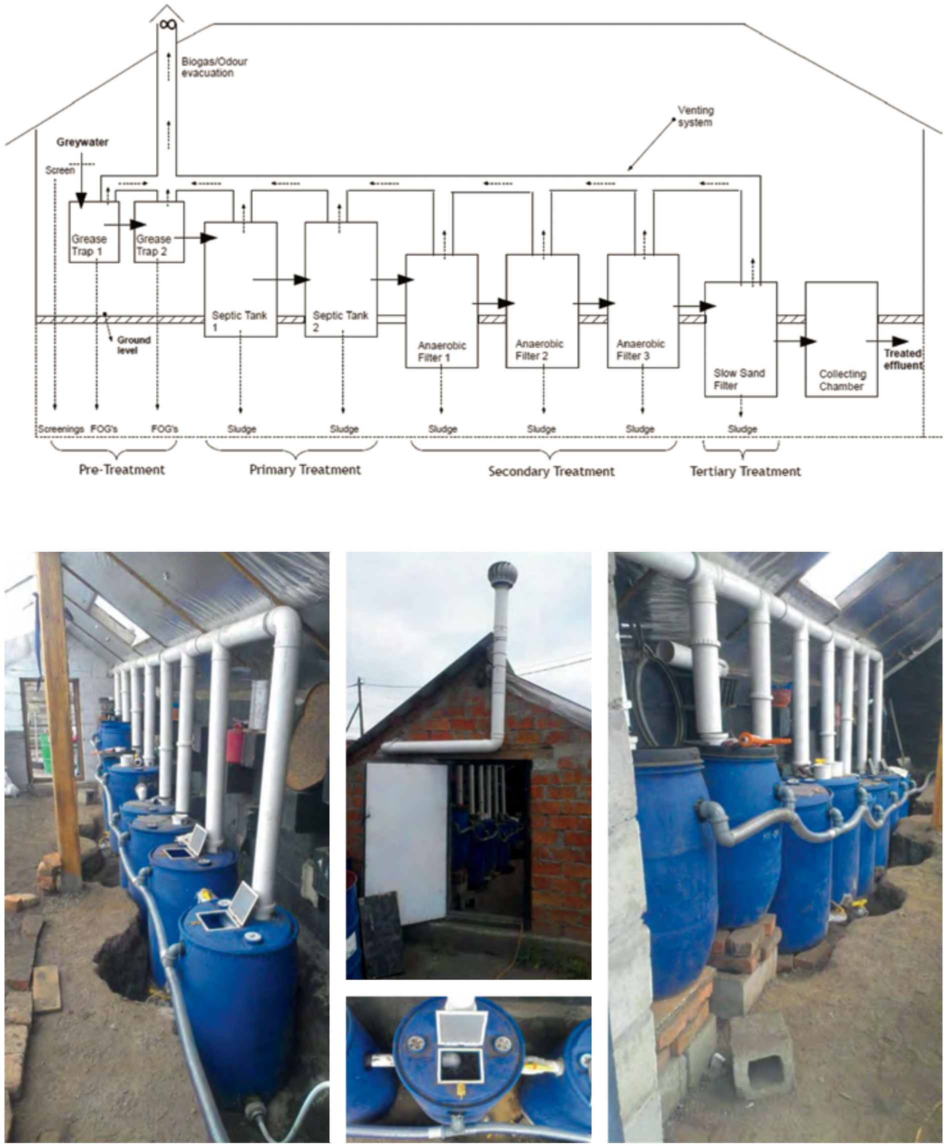


FIGURE 3-7 FLOW DIAGRAM (ABOVE) AND PHOTO (BELOW) OF GREENHOUSE GREYWATER TREATMENT UNIT.

PASSIVE SOLAR GREENHOUSE

A passive solar greenhouse (Figure 3-8) was constructed for GH-GWTU by a French NGO called The Renewable Energy and Environmental Group (GERES) based on the Mongolian climatic patterns and geographical settings [202].

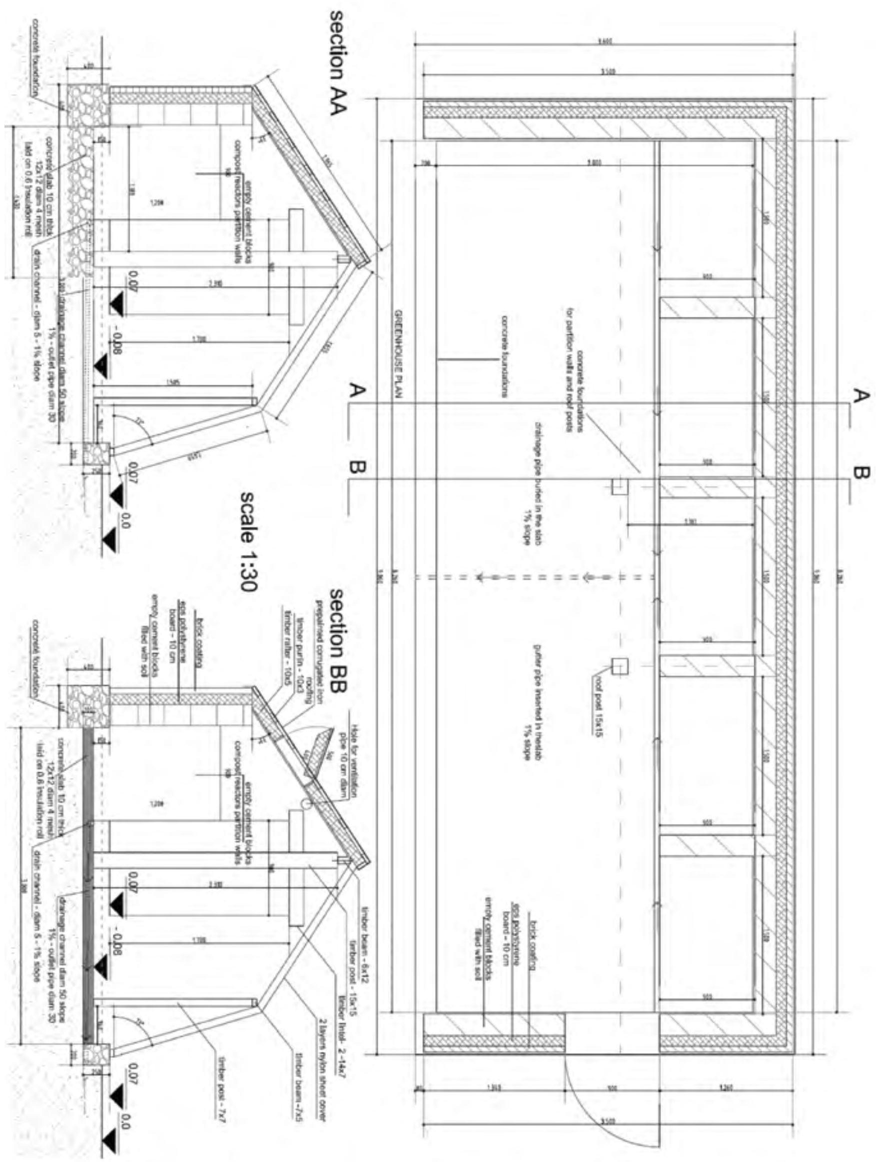


FIGURE 3-8 GREENHOUSE THAT DESIGNED AND USED FOR GREYWATER TREATMENT SYSTEM.

MAJOR DESIGN COMPONENTS OF GH-GWTU

Grease trap

Greywater from Ger areas contains high amounts of fat, oil and grease (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 FOG's it is prevalent to install a grease trap as a pre-treatment technology which is a simple method applied in small-scale greywater treatment system [203]. For the GH-GWTU a dual compartment grease trap (Figure 3-9) was installed.

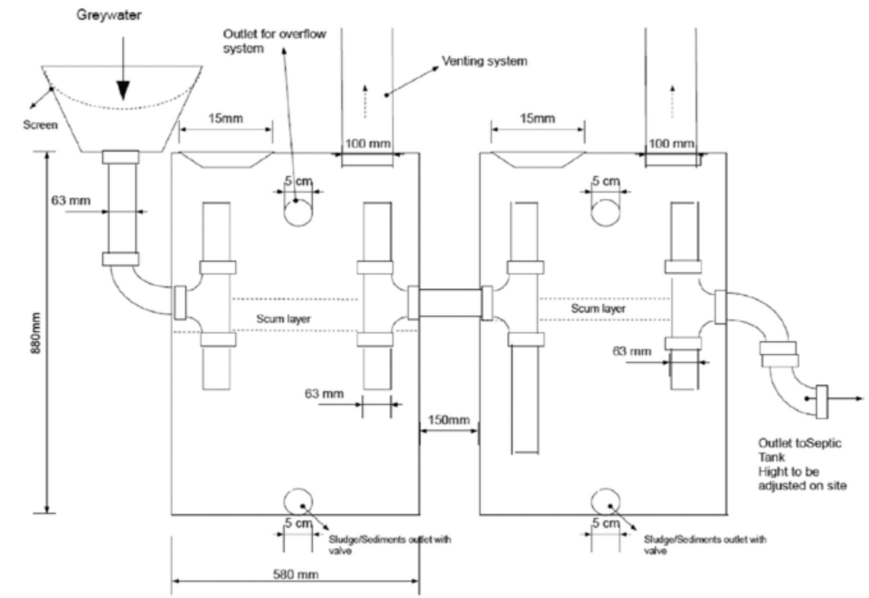


FIGURE 3-9 GREASE TRAP

Septic tank

Septic tanks are making use of gravity separation, thus, a combination of sedimentation and flotation. Septic tanks mainly focus on the sedimentation of particles instead of on 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 [203]. The septic tanks at the GWTUs are designed with HRTs around 5-6 days to enable the sedimentation of small material and therefore minimize pressure on following treatment steps. Septic tanks are placed at GH-GWTU as technology for primary treatment (Figure 3-10). The capacity of the septic tank for the system 60l/d.

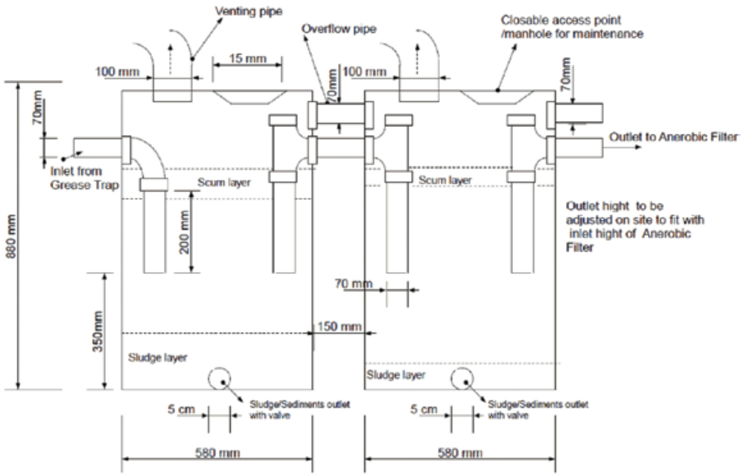


FIGURE 3-10 SEPTIC TANK

Anaerobic gravel filter/up-flow gravel filter

Upflow roughing filters (UFRF) (Figure 3-11) are fixed bed reactors that are frequently used for secondary treatment of household greywater [203]. 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. The filter media of the roughing filter at the GHTU is gravel which is chosen due to good accessibility and affordability in UB. The UFRF at the GH-GWTU is operated in series and consists of three plastic barrels that each holds a loading capacity of about 160 liters. The complete series respectively has a total volume of roughly 480 liters. 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).

The grain sizes are purposely chosen rather high to achieve higher pore volume and therefore to minimize 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 with about 8 days. A by-product of the anaerobic digestion is the production of inflammable methane and foul odor, for the evacuation 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 (Figure 3-8-photo below). The top gravel layer is covered with a water level of some centimeters. 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.

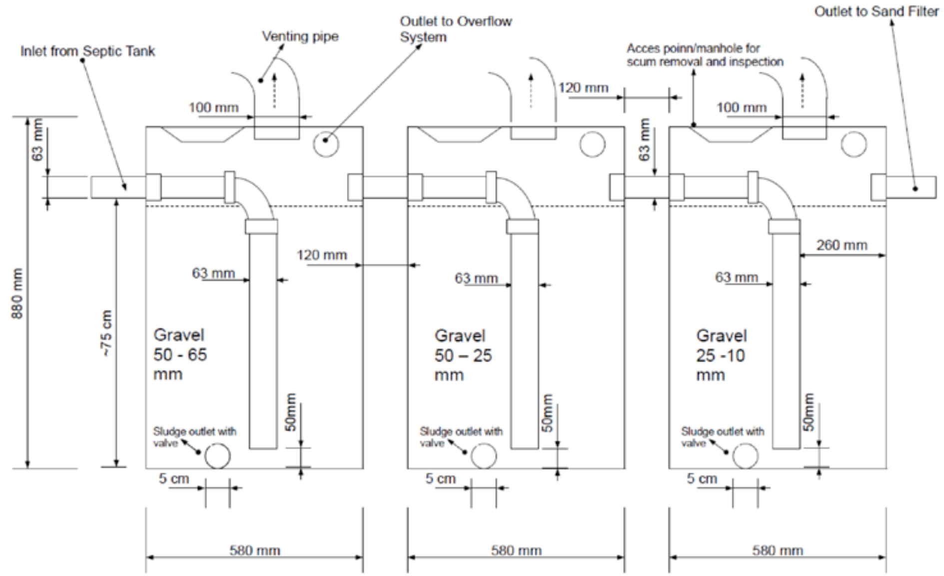


FIGURE 3-11 UP-FLOW GRAVEL FILTER

Slow sand filter

Slow sand filters (SSF) (Figure 3-12) are commonly combined with UFRF to achieve higher water quality of the effluent [204]. In many cases SSF are used to produce a potable product which is due to its high efficiency in the reduction of pathogens. In the case of the GH-GWTU it is designed primarily to minimize 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 MO (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 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 metabolized by its population.

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 (0.15-0.35 mm) [205] to avoid plugging. 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 biofilm reduces the performance of treatment. This should be undertaken once per month and carried out through the provided manhole.

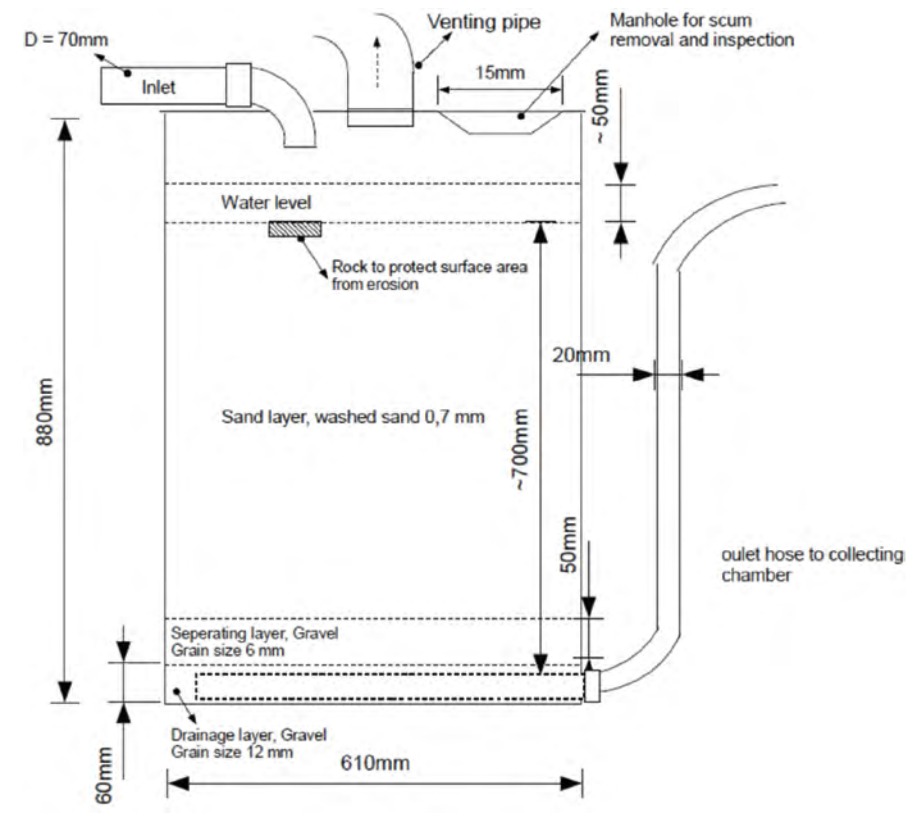


FIGURE 3-12 SLOW SAND FILTER

HRT and main working mechanism

TABLE 3-1 HYDRAULIC RETENTION TIME AND MAJOR WORKING MECHANISM.

MAJOR COMPONENT	HYDRAULIC RETENTION TIME	WORKING MECHANISM
Grease Trap	2 days	Physical processes- Seperation of FOGs by flotation and separation of solids by sedimentation.
Septic Tank	5.4 days	Physical processes- Seperation of FOGs by flotation and separation of solids by sedimentation.
Anaerobic Filter	8 days	Mainly biological degradation through anaerobic digestion. Additionally, physical and chemical process.
Slow Sand Filter	12 hours	Mainly biological degradation through anaerobic digestion. Additionally, physical and chemical process.

SYSTEM MONITORING, WATER QUALITY ANALYSIS AND DATA COLLECTION

The household members were requested to dispose of greywater manually in the system. The system was monitored and the water quality was tested at the National Accredited Central Laboratory under the national Ministry of Environment and Green Development. Different chemical and biological parameters were analyzed for greywater from five different sections of the GH-GWTU.

The chemical and biological parameters include: Total Suspended Solid (TSS); Chemical Oxygen Demand (COD); NH_4^+; NO_2^-, NO_3^-, PO_4^-, and total *E. coli*. As there is no standard in Mongolia on household greywater treatment and reuse, the system performance with the discharge standard of pollutants for municipal wastewater treatment plants of neighboring China has been evaluated [206]. In addition, the available parameters of pollutants and the environmental discharge standard of industrial effluent in Mongolia was also evaluated [207]. Lastly, temperature data was collected manually during the sampling period to assess any effect on the treatment process.

3.3.2 EXPERIMENT ON 'ICE-BLOCK' GREYWATER TREATMENT UNIT

SYSTEM DESIGN AND CONSTRUCTION

In addition of GH-GWTU, an 'Ice-Block Greywater Treatment Unit (IB-GWTU)' was designed, constructed and tested for greywater treatment during the summer period (July-September) of 2013 in the peri-urban Ger (informal settlement) areas of Ulaanbaatar, Mongolia. This system is based on storing water during the entire winter freezing period as an ice block, and then starting treatment during the summer/non-freezing period. Three major components (storage pond—septic tank—constructed wetland) were set up at the household level (Figure 3-13 to Figure 3-18). Storage capacity for 7.5 months (mid-October to May) corresponding to 225 days for three residents was tested with a consumption of 8 l/person/d (24 l/d x 225 d = 5400 l).

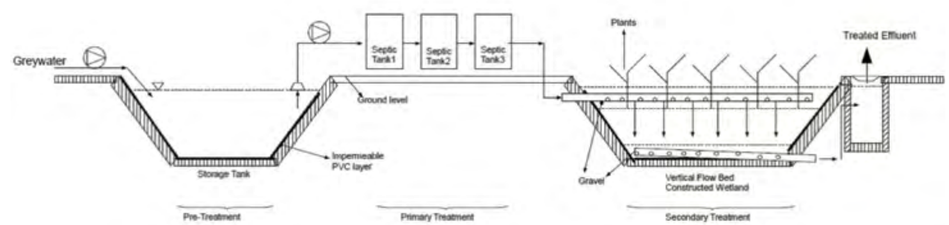


FIGURE 3-13 SCHEMATIC DIAGRAM OF ICE-BLOCK GREYWATER TREATMENT UNIT (IB-GWTU).

FIGURE 3-14 SYSTEM CONSTRUCTION STAGES.

FIGURE 3-15 SIDE VIEW OF THE IB-GWTU.

MAJOR DESIGN COMPONENTS OF IB-GWTU

Storage pond

Storage pond of IB-GWTU (Figure 3-16) serves as greywater storage for the winter 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 and capita. 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 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.

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

Where:
G (ground area) = 1m2
S (surface area) = 8.4m2
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 is 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 in fine sand. The principles of septic tanks for the IB-GWTU are the same like the septic tanks installed in the GH-GWTU.

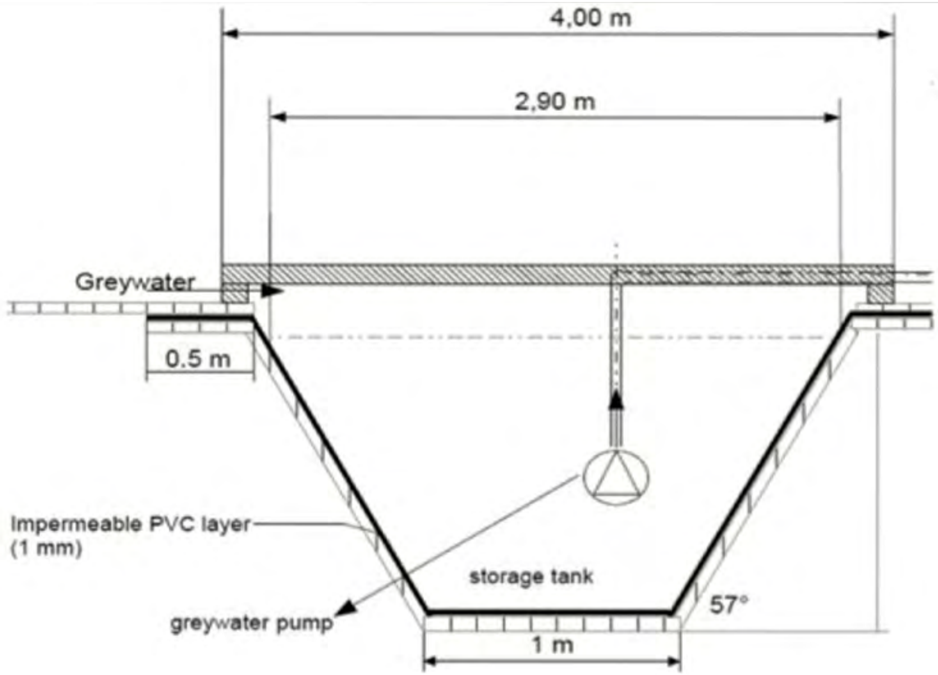


FIGURE 3-16 STORAGE POND FOR IB-GWTU

Constructed wetland

The selection of the appropriate option for constructed wetland (CW) depends on various factors such as e.g. area requirements, climate and financial aspects. Based on those, the CW designed for the IB-GWTU applies subsurface water level, vertical flow (VF), downflow and gravel as filter media. Subsurface flow is chosen based on the fact that it does not contain open water bodies and therefore mosquito breeding and odor production are limited. Vertical flow is applied because area requirements are lower in comparison to horizontal flows (Morel and Diener, 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 3-17.

The depth of the filter bed is about 1m which represents a typical value for vertical flow constructed wetlands [208]. The surface area of the CW is about 16m^2 and 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 <10ºC. 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)
Production during that time is 3*8 l/d*225d = 5,400
5 people live on the compound during summer (4.5 months → 140 days)
Production during that time is 5*8 l/d*140d = 5,600l

Greywater water 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 [203]. The size is achieved through thoroughly screening and sorting out of gravel. 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.

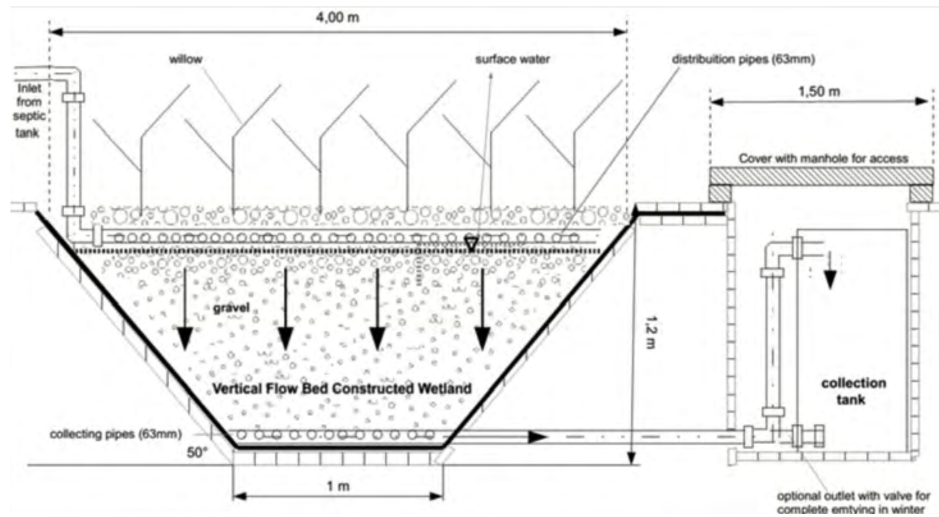


FIGURE 3-17 CONSTRUCTED WETLAND FOR IB-GWTU

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 der top gravel layer. After passing the gravel zone the water is collected with a drainage system on the bottom of the bed. The pipe networks are built of dia 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.

HRT and main working mechanism

TABLE 3-2 HYDRAULIC RETENTION TIME AND MAJOR WORKING MECHANISM OF IB-GWTU.

MAJOR COMPONENT	HYDRAULIC RETENTION TIME	WORKING MECHANISM
Storage Pond	-	Physical processes- Separation of FOGs by flotation and separation of solids by sedimentation.
Septic Tank	6 days	Physical processes- Separation of FOGs by flotation and separation of solids by sedimentation.
Vertical Constructed Flow Wetland	8 days	Mainly biological degradation in biofilm. Additionally, chemical adsorption and physical processes.

SYSTEM MONITORING, WATER QUALITY ANALYSIS AND DATA COLLECTION

The residents from the household were requested to dispose of greywater manually/pumped in the IB-GWTU. The system was monitored and samples were collected for testing at the Chemical Laboratory of National University of Mongolia, Ulaanbaatar. Different chemical and biological parameters were analyzed for greywater from each step of the system based on ISO standard methods. Treatment was subsequently monitored to analyze the water quality both for chemical (e.g. TSS, COD, N-NH^{+4}, PO_4^-) and biological (e.g. *E. coli*) parameters, and to assess the technical feasibility, adaptability, and potentiality in Mongolian cold climate condition.

As there is no standard in Mongolia on household greywater treatment and reuse, the system performance with the discharge standard of pollutants for municipal wastewater treatment plants of neighboring China has been evaluated [206]. In addition, the available parameters of pollutants and the environmental discharge standard of industrial effluent in Mongolia was also evaluated [207].

3.3.3 GREYWATER CUSTOMER SURVEY AND POLICY DIALOGUE

A household survey, with structured questionnaire, was conducted between June and August 2014 in the peri-urban (Ger) areas of Ulaanbaatar, Mongolia, among the users of ACF sustainable sanitation (SS) technologies and services. The survey assessed customer satisfaction, their willingness to pay for the greywater treatment and reuse, knowledge and attitude about it. Eighty households were interviewed out of 350 SS technology users.

A policy dialogue has been organized in March 2014 and the situation and possibilities of greywater treatment and reuse options in Mongolian context were discussed. Several government agencies, universities and NGOs were the participants for spontaneous discussion on the greywater issue for the Ger areas. The summary and key outcomes of the discussions were analyzed.

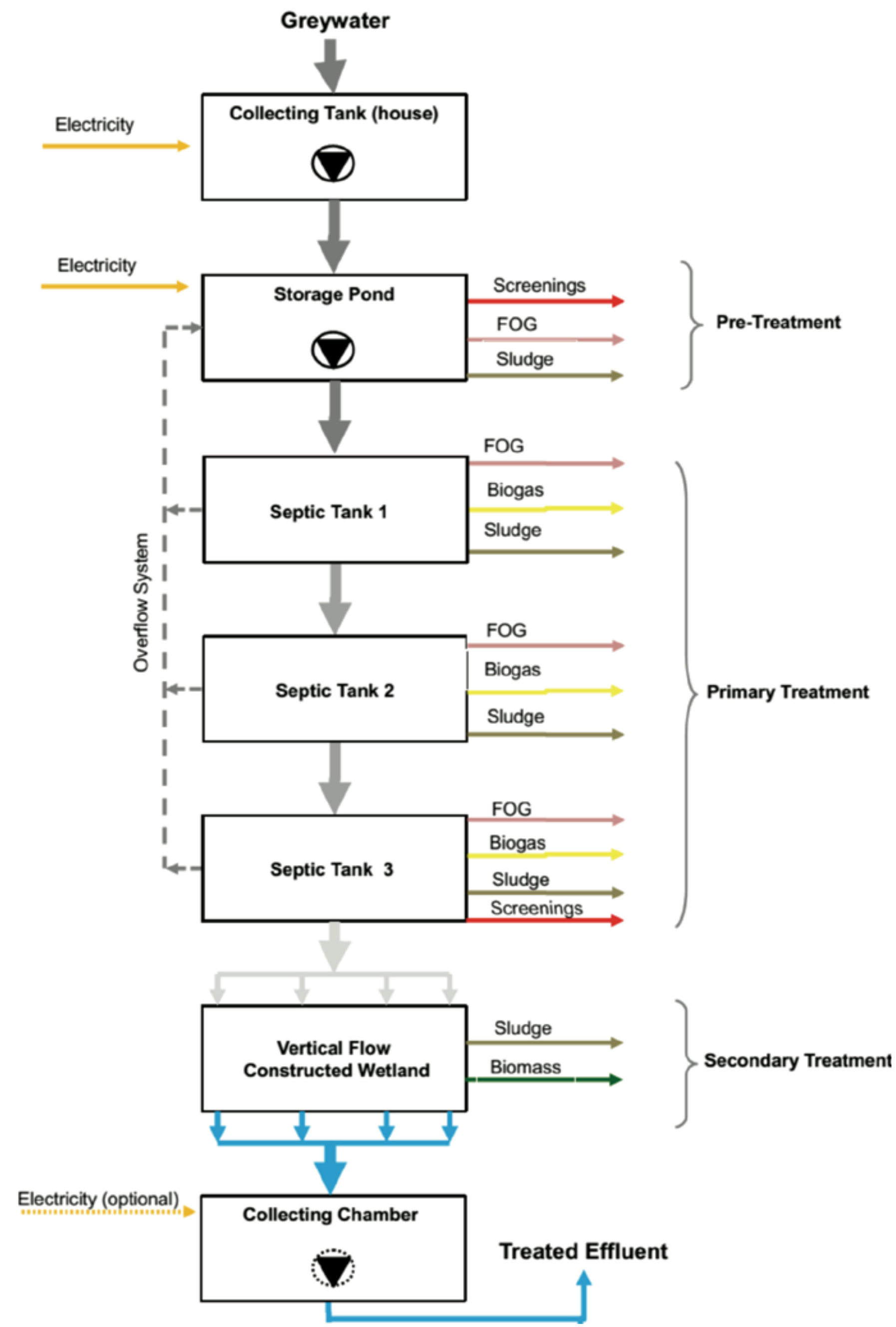


FIGURE 3-18 FLOW DIAGRAM OF IB-GWTU

3.4 ONSITE EXPERIMENTS ON HUMAN FECES TREATMENT SYSTEMS

3.4.1 TECHNICAL EVALUATION: FIELD OBSERVATION AND INTERVIEWS

The evaluation was carried out through observation of all technical components and steps (eco-toilets, emptying services, collection-transportation-storage system, treatment facilities, and application of the products) using 10 transect walks in the study area. 72 out of 120 eco-toilets built by ACF were technically evaluated and observed in order to assess technological benefits and shortcomings and the status of maintenance and operation. All the toilets were installed outside the Ger houses and inside the main compounds in the peri-urban Ger areas. Toilets are separated from the households due to the socio-cultural reasons. Almost all pit latrines in the Ger areas are not attached with the household because of this reason.

The emptying service systems and activities were observed and the emptying service staff were interviewed as key informants to identify the problems encountered during the roll-out of the services, seasonal suitability and frequency of emptying cycles during one-year period. Collection, transportation, storage and treatment systems of fecal matter was monitored to evaluate the processes and to address any challenges and opportunities for future improvements.

3.4.2 EMPTYING, COLLECTION AND TRANSPORTATION OF FECES

All toilets in the world are either manually or mechanically emptied. Manual emptying is the most commonly used, especially areas with water scarcity, slum, bad terrains and lack of centralized sewerage system. Human feces are collected from these toilets. For this study the emptying staff have been trained to perform the emptying service, collection and transportation of fecal matter to the trearment (composting) site. At every three months interval, emptying services were carried out by ACF from household to household.

Feces were collected in 120l of steel containers that were placed beneath the toilets' superstructures, while urine was diverted since there is no market or application for now in Mongolia due to socio-cultural barrier. Fecal matter was transported by using truck to the composting site. At the moment, the capacity of the truck has been increased from 8 to 16 buckets/trip; this is to safe the cost of transportation, energy and period of emptying service. On getting to the site, the containers were emptied into big barrels of 220l and stored in the storage facility over winter period, and later put to use (composting) in the next summer.

3.4.3 TREATMENT OF HUMAN FECES: COMPOSTING COMPOSTING HUMAN FECES

Two different technologies of human feces composting were applied Semi-Centralized Winter Composting Unit (SC-WCU) and Semi-Centralized Greenhouse Composting Unit (SC-GHCU). Two greenhouses were constructed (Figure 3-9), one for compost maturation and another for composting in 2013. The principle of SC-WCU is to run composting during the winter period and the SC-GHCU is for extending the summer composting for getting more output of the compost. Temperature effect was monitored by using automatic hobo data-logger for both composting processes to assess the technical feasibility in the cold climatic condition.

COMPOSTING SITE

The site was located at the outskirt of Ulaanbaatar, which was about 30km drive from the center of the Ulaanbaatar city. Both SC-WCU and SC-GHCU were constructed on the site by Action Contre la Faim (ACF) Mongolia.

Figure 3-21 and Figure 3-22 show the pictorial diagram of both composting facilities. Figure 3-19 and Figure 3-20 shows the organization of four trial bins for the SC-WCU, while the fifth trial was later conducted in SC-GHCU. Other facilities such as: storage, office, water supply, security house, staff protection, greenhouse for maturation and fence across the site, were also installed on the site.

SUBSTRATS FOR CO-COMPOSTING

The fecal matter used in these trials were collected in the container beneath the toilet's superstructure and manually emptied at the interval of three months, then transported to the semi-centralized composting facility for proper composting and hygienization. The co-composting materials that were used as carbon sources are: wood chips, sawdust, straw and food waste, they were locally obtained at the open market and sawmill station. Preliminary activities such as: sorting, shredding (1~5cm) and separations were conducted before mixing with fecal matter. Physicochemical properties such as moisture content (MC), total carbon (TC), total nitrogen (TN), and C/N of all the used feedstocks were determined before mixing. The C/N ratio of each trial was in the range of 1:27~29. Little warm water was sprinkled to the piles to maintain moisture content within the range of 55-65%, while pH was maintained within 6.5-7.0 at the initial stage. The mixing ratios (in volume) of all the trials are shown in Table 3-3. The composting trials were conducted for over a month when the pile temperatures dropped down to the ambient temperature.

TABLE 3-3 COMPOSTING TRIALS (1-4) CONDUCTED IN SC-WCU (JUL-AUG 2013)
AND TRIAL 5 IN SC-GHCU (SEP-NOV 2013)

FEEDSTOCK	MIXING RATIO	MC (%)	TC (%)	TN (%)
TRIAL 1				
Feces	1	87	48.5	4.5
Sawdust	1	8	55	0.1
Straw	1	7.7	51	0.6

FEEDSTOCK	MIXING RATIO	MC (%)	TC (%)	TN (%)
TRIAL 2				
Feces	1	87	48.5	4.5
Woodchip	1	13	54	0.15
Straw	1	7.7	51	0.6
TRIAL 3				
Feces	1	87	48.5	4.5
Sawdust	1	8	55	0.1
Woodchip	1	13	54	0.15
TRIAL 4				
Feces	1	87	48.5	4.5
Sawdust	1.5	8	55	0.1
TRIAL 5				
Feces	1	87	48.5	4.5
Sawdust	1	8	55	0.1
Straw	1	7.7	51	0.6
Food Waste	1	78.5	29.1	0.8

EXPERIMENTAL SET-UP AND DESIGN

Bin composting using SC-WCU

The first four trials were conducted in four different waste bins of 660l that were used as reactors. The bins were arranged in the composting room. As shown in the experimental design, each bin was fully covered with styrofoam of 150 mm thick to protect the heat lost and influence of ambient temperature. On top of each bin, ventilation pipe of diameter 10 cm was attached to carry out the toxic/off-gases and odor from the room. The perforated boards for carrier plates were placed at 10 cm from the base of the reactors to support the composting bed and ensure uniform aeration. Also, at the base of each reactor, the holes were drilled for aeration and leachate collections. The compost temperatures were hourly monitored with data loggers (http://www.onsetcomp.com/products/data-loggers/u12-006) and the probes were diagonally placed inside the bins to determine the temperature at the top, core and bottom of the piles. The monitored data were offloaded via Hobo shuttle (http://www.microdaq.com/occ/accessories/u_shuttle_data_transporter.php) and transferred into computer for analysis.

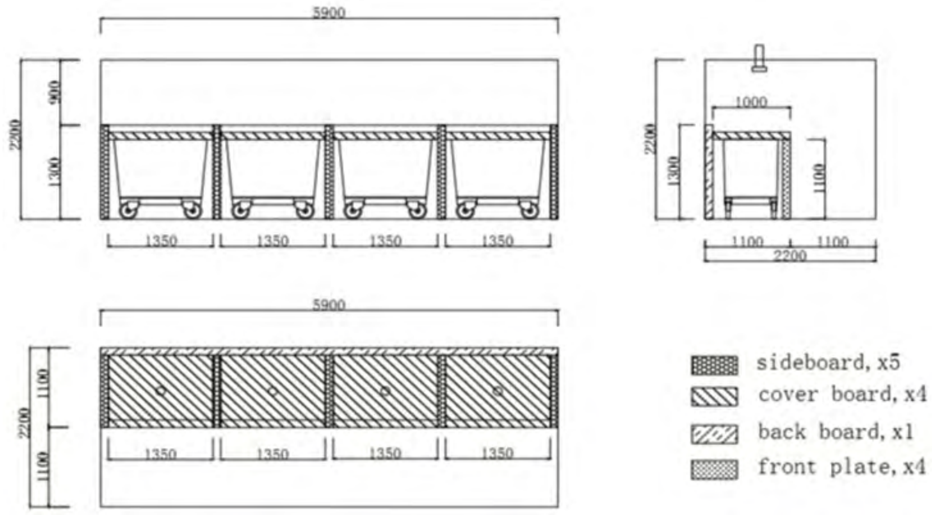


FIGURE 3-19 SCHETEMATIC DIAGRAM OF THE BINS IN THE SEMI-CENTRALIZED WINTER COMPOSTING FACILITY.

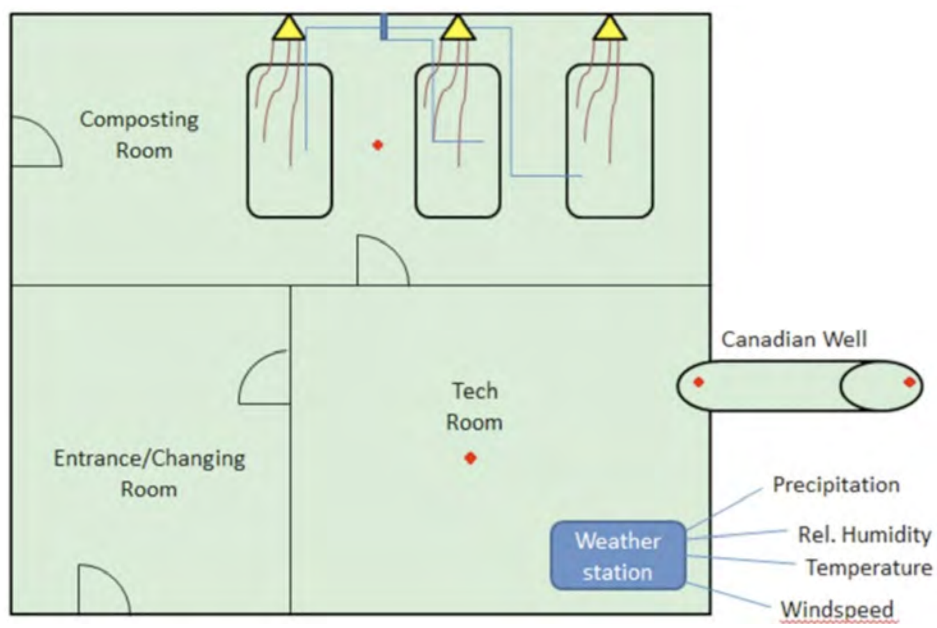


FIGURE 3-20 SCHEMATIC DIGRAM OF SC-WCU

Ventilations across the piles in all the reactors were intermittently maintained and supplied (at 30 min off & on with the help of stop clock) at 0.5l Kg-1 min-1 (dm) from bottom of each reactor that were simultaneously operated. Turning was manually carried out with pitchfork on weekly basis (7 days interval) to allow every part of the compost to be exposed to heat for pathogens destructions and also to enhance all carb on and nitrogen to be supplied to microorganisms.

FIGURE 3-21 ECO-TOILET ORIENTED SEMI-CENTRALIZED WINTER COMPOSTING UNIT.

Semi-Centralized Greenhouse Composting Unit

The fifth trial was conducted to find out the feasibility of composting process in SC-GHCU using greenhouse technology which was the similar greenhouse design constructed for greenhouse greywater treatment unit. The primary ideas for greenhouse concept were (1) to reduce operation and maintenance cost (2) to effectively utilize the higher ambient temperature generated in the greenhouse, in order to enhance the composting process and hygienization and (3) to extend the composting period up to Mid-November since winter season runs in Mongolia for almost 8 months from October to May. The arrangement of compost pile and mixing process are shown in Figure 3-24 and Figure 3-25.

FIGURE 3-22 ECO-TOILET ORIENTED SEMI-CENTRALIZED GREENHOUSE COMPOSTING UNIT.

Passive aeration was adopted to evenly distribute ambient air across the pile, which diffuses through the bored blocks and slanted planks against the wall. The composting pile was stacked to a volume of about 1.2m^3, which was 80% of the inner volume of the slot. For this technology, one of the challenges was the ability to properly and thoroughly mix the composting piles with pitchfork. This mixing process was very tedious and involves lots of energy; otherwise, there is need for small mechanical device to carry out this operation, not only to properly turn the piles, but also for the safety of the operator. In this trial, a data logger was horizontally placed at the center of the pile and the average temperatures were recorded throughout the composting process. The turning period was fortnightly (2 weeks interval) carried out, not only to reduce the stress of the labor, but also to minimize ammonia volatization.

ANALYTICAL METHODS

The following analytical parameters for effective composting were conducted in Mongolia State University of Agriculture in order to supply the required nutrients to microbes and to study the process stability. MC, TS, and TC were determined according to the APHA standard methods. pH (1:10 w/v compost:water extract) was measured with a hand-held pH meter (HANNA HI9125N, Italy), while TKN was analyzed by Kjeldahl method. The process stability on CO2/O2 was monitored on the field by biogas analyzer (Geotech-Biogas 5000, UK) to check for the aeration requirement for the piles. Different heavy metals such as As, Pd, Cd, Cr, Cu and *E. coli* content in the compost products were also analyzed at the Chemical Laboratory of National University of Mongolia to assess the safety of the composts and their applications.

3.5 RESEARCH METHODS ON SOCIAL ACCEPTANCE AND EXPLORING FUNDING FOR THE REPLICATION OF TECHNOLOGIES

The main research method was to conduct interviews with community members (clients), institutional stakeholders and key informants (the key persons from the institutional stakeholders and communities who were interviewed informally).

3.5.1 QUESTIONNAIRE SURVEY

A household survey, with structured questionnaire, was conducted between June and November in 2013 in the peri-urban (Ger) areas of Songinokhaikhan and Bayanzurkh Districts of Ulaanbaatar, Mongolia, among the users, non-users and service receivers of SS technologies (i.e. eco-toilets) and services (i.e. emptying services). The survey assessed community perceptions on financing sustainable sanitation, income generation, willingness to pay for the technologies and services and their benefits. The survey was conducted amont the 72 households out of 120 of eco-toilet users and equal number of non-users was also interviewed during the the questionnaire survey.

3.5.2 SEMI-STRUCTURED KEY INFORMANT INTERVIEW

In addition, to ensure triangulation of the household survey result, a total of 10 institutional stakeholders and 10 key informants from government and non-government organizations, healthcare institutions/hospitals, insurance and banks, service and business providers, and companies were interviewed using a semi-structured questionnaire throughout the year of 2013, to assess views/perceptions on financial sources, future financing in the sector and willingness to provide finances and business opportunities.

3.6 STRENGTHS, WEAKNESSES, OPPORTUNITIES AND TREATS ANALYSIS

This study applies SWOT as a research tool, which presents several applications in business [209], environmental management [210], solid waste management, and energy planning and sustainable energy development studies [211, 212]. However, SWOT has never been applied in water, sanitation, and hygiene (WASH) studies.

The WASH-related scenarios in Ulaanbaatar are investigated through qualitative field investigations, such as transect walk, focus group discussions (FGDs), and semi-structured interviews with community members and stakeholders. The SSS-SWS integration scenario has been developed based on the findings from this research and the existing literature, discussions, and expert interviews.

3.6.1 TRANSECT WALK

Five transect walks are performed with the help of key informants and local staff members from ACF Mongolia to observe, listen, learn, and familiarize the Ger area, as well as to identify the problems, conditions, and structure of the settlements. The existing practices and technologies in these areas (i.e., types of toilets, greywater discharge systems, and hygiene scenarios) are addressed and noted during the transect walk for the SWOT analysis.

In addition, research based on field observations was carried out by transect walks, which involved community members and key informants through the area from one side to other, observing, asking questions, and listening [213]. Five transect walks were carried out in five different geographic areas with key community actors and ACF Mongolia WASH team members to characterize WASH and environmental conditions. The observations revealed implications of solid waste dumping, greywater discharge, toilet conditions, availability of water near toilets for hand-washing, water collection systems, and water storage systems at the household level.

3.6.2 KEY INFORMANT INTERVIEWS

Fifteen semi-structured key informant interviews are performed with community members, sector stakeholders, government officials, university teachers, and community-based organizations (CBOs). WASH-related questions are asked during the interviews. The interviews are likewise audio/video recorded by the authors to facilitate the SWOT analysis. The recorded interviews are repeatedly checked to validate the gathered and analyzed interview data.

In addition, five community-based representatives, five NGO officials, two doctors, three health care officers, and three university faculty members were chosen as key informants for interviews to ascertain the major sources of WASH-borne hazards in the Ger areas. Community-based leaders proved very knowledgeable about WASH-related issues, including health implications. Representatives from ACF Mongolia, World Vision Mongolia, UNICEF Mongolia, ECO TV, and district health offices were considered key informants for a comprehensive diagnostic of the WASH situation in the area of interest and, moreover, to conceive of possible solutions to solve principal WASH-borne challenges. In addition, three faculty members from the Mongolian University of Science and Technology, Mongolian State University of Agriculture, and the National University of Mongolia were interviewed to inform proper solutions for reducing WASH-borne hazards in the study area.

3.6.3 FOCUS GROUP DISCUSSION

Ten stakeholders are interviewed, and six members of CBOs have participated in an FGD during the ACF WASH conference in Ulaanbaatar. Another FGD is performed during the International Conference on Water Research in Singapore in January 2013 to obtain supplementary views/opinions. Questions on WASH and SWS–SSS integration are asked during these sessions. Mongolian translators are likewise present during these sessions.

3.6.4 DRINKING WATER QUALITY ANALYSIS

Drinking water quality was analyzed to assess the chemical and pathogenic contamination to envisage the possible hazards and threats on human health and environment in Ger areas. A total of 250 water samples were collected through random sampling, including from 210 households and 40 water kiosks (water collection points) from the Ger areas during the winter period of December 2012 and January 2013. Additionally, a similar quantity of samples was analyzed in the summer period of May and June 2013 to compare the seasonal state of water quality both at the household level and at water kiosks. All of the water samples were analyzed by the National Accredited Professional Inspection Central Laboratory of Ulaanbaatar in Mongolia. Three parameters were analyzed: biological *E. coli*, chemical hardness, and pH, in order to identify drinking water contaminants and their sources. Furthermore, greywater generated from households was tested to ascertain chemical characteristics, which might have additional impacts on human health and environmental conditions in Ger areas.

3.6.5 STRUCTURED QUESTIONNAIRE SURVEY

A WASH-focused structured knowledge, attitude, and practice (KAP) survey, which serves as an educational diagnostic of the community, was also conducted by ACF Mongolia at 210 households in Ger areas at the end of 2012. Multiple choice questions where more than one answer could be chosen were asked to the respondents. The sites selected for the KAP survey are the Ger districts of Ulaanbaatar where the current ACF WASH program is being implemented. Intervention areas were selected based on several factors, such as population density, poverty level, and water and sanitation accessibility. The cluster sampling method was applied, due the large population size and scattered households in the intervention area. According to ACF & WHO sampling standards and methodology [214] —where a statistical accuracy of 10% precision is preferred— the total sample required was 210 households. Households were randomly selected for interviews in each residential cluster. The questions developed covered a range of topics related to domestic water, sanitation and hygiene practices, family health status, and waterborne disease transmission. SPSS was used to analyze all data collected through these structured questionnaire survey.

30 clusters, the total sample required, (including the doubling of samples to avoid the 'cluster effect') was calculated as 210 households. This was calculated using the following formulas:

$$N = \frac{t^2(p \times q)}{D^2} = \frac{1.96 \times 1.96(0.5 \times 0.5)}{0.1^2} = \frac{3.8415 \times 0.25}{0.01} = 96.04 \approx 96$$

The sample size:	N
The error risk:	t
The expected	p
prevalence:	q=1-p=0.5
	d=0.1 (as the accuracy range is 10%)

The degree of accuracy:

To avoid the cluster effect, sample size was doubled.

N=96 x 2 = 192

Number of cluster is decided as 30 according to limitation of time and human resource capacity.

Number of households in a cluster is 7.

192/30=6.4≈7 7 x 30 = 210

Number of households in the survey is 210.

Moreover, an observational study and structured survey were carried out by ACF Mongolia with students and teachers from eights schools (three primary schools, three middle schools, and two high schools) to assess WASH conditions in schools. One hospital in the Ger area was likewise subjected to an observational study and semi-structured key informant interviews to gain further insight into hygiene issues and practices.

4 - ONSITE EXPERIMENTS ON HOUSEHOLD GREYWATER AND HUMAN FECES TREATMENT

4.1 HOUSEHOLD GREYWATER MANAGEMENT AND TREATMENT

4.1.1 CURRENT SITUATION

The results from the KAP survey among the households of the Ger areas show that 51.4% households did have soak-pit in their compound to discharge greywater and 40% households pour greywater into their pit latrines. The other households discharge greywater onto the roads, in the yards or at other places. Practice of the Ger residents for discharging their greywater into pit latrines, soak-pits, yards, and on the open streets cause immediate environmental pollution and health hazards to the Ger inhabitants. The reasons for not having any disposal facility are the lack of space, rocky ground, limited time and human resources to deal with greywater and shallow groundwater. Field observation confirmed that there is no drainage system where greywater can be disposed of for any kind of treatment in the Ger areas. The Ger areas were not connected to any centralized or decentralized sewer system a fact that forces them to practice uncontrolled greywater disposal to the environment. Public Bath Houses are equipped with contingency wastewater tanks that are emptied when full; the private operator of the Bath House bears the cost for this service.

Disposal of greywater inside or outside the compound is a very common practice. Reason for this behavior is the fact that in winter the greywater freezes in the pit latrine or soak pit and considerably reduces the effective volume of the pit. Therefore households pour it in the compound or on the street, causing considerable ice hazards. As people maintain the same attitude in the warmer months this may considerably degrades the environment and provides favorable conditions for vectors to breed [215].

4.1.2 GREYWATER CHARACTERISTICS IN GER AREAS

The laboratory analysis shows (Figure 4-1) the high concentration of chemical oxygen demand (COD) (range from 6,072 mg/l to 12,144 mg/l), N-NH_4^+ (range from 183.7mg/l to 322.6 mg/l), PO_4^{3-} (range from 12.6 mg/l to 88.2 mg/l) and total suspended solids (TSS) (range from 880 mg/l to 3,200 mg/l) which are much higher than in any other country [84, 216]. The values are even much higher than the norms provided by the WHO (2006) guidelines (e.g. COD is 366 mg/l, TSS is 162 mg/l and N-NH4+mg/l). In addition, the average greywater generation in the Ger area households was 4 liter/person/day with an average range of water consumption of 8-10 l/person/d [39]. The greywater generation is much lower in the Ger areas than in other countries such as, 66 l/person/d in Jordan and 70 l/person/d in Germany [84, 216].

The concentration of COD in mg/l has correlation to the total amount of greywater per person, which is 4 l/d. This value confirms the assumption that about 40-50% of the freshwater delivered is available as greywater in the study area. The high phosphate content in the sample No. 1 is due to washing powder used for laundry purpose.

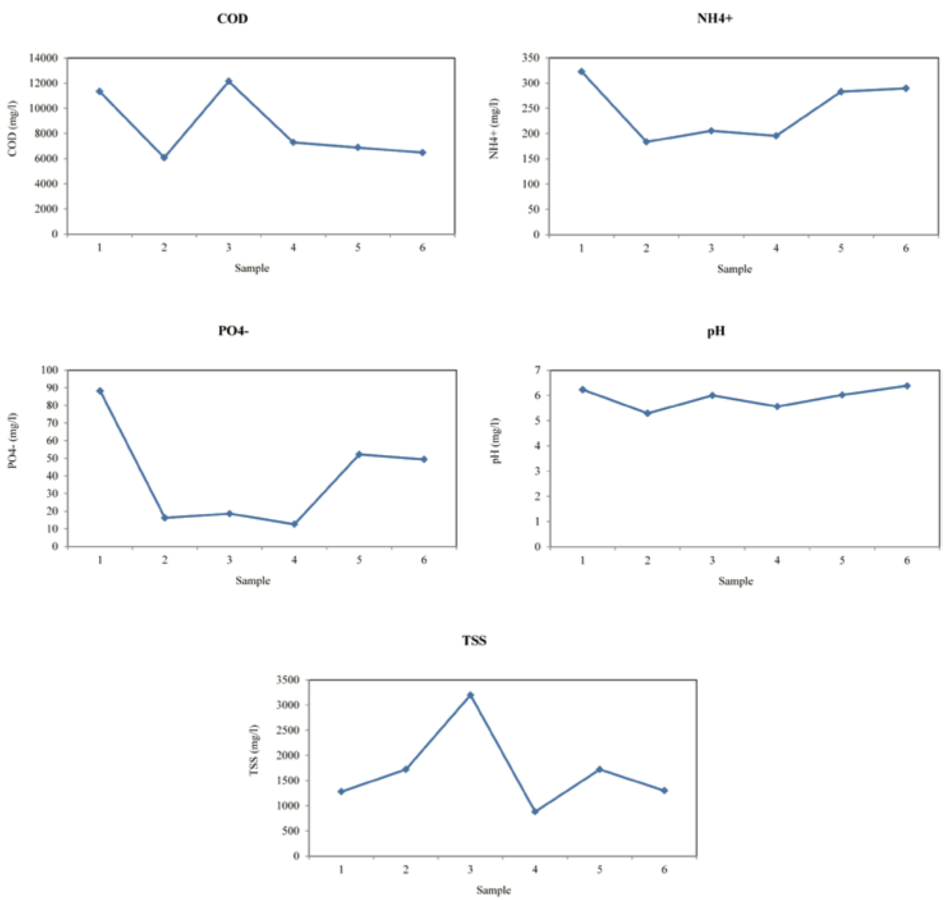
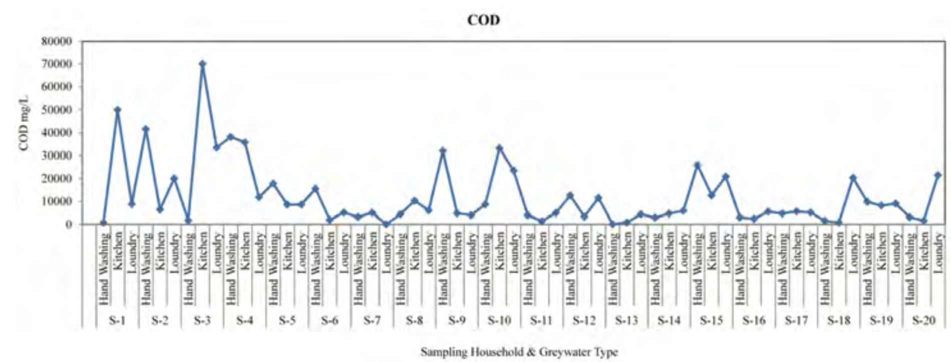
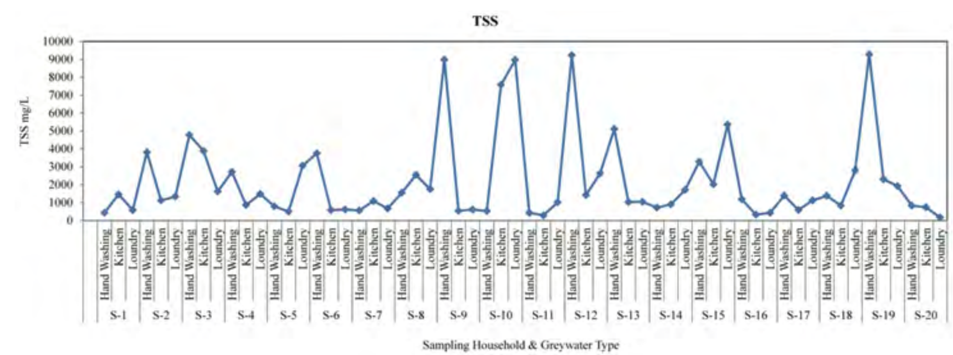


FIGURE 4-1 CHEMICAL TESTS RESULTS OF SIX RANDOMLY SAMPLED HOUSEHOLDS.

From previous analysis of greywater in Ger households [217] very high concentrations of chemical parameters were found. The analysis carried out by the Water Supply and Sewage Authority (USUG) Laboratory of Mongolia (Figure 4-2A&B and Table 4-2) illustrates the concentration of chemical parameters found in the greywater, with particular emphasis on the chemical oxygen demand (COD). The sampled (n-20) were collected based on random sampling methods by USUG due to the scattered households in the Ger areas and limited resources. The parameters measured from a majority of household samples were substantially higher than the COD and total suspended solids (TSS) of the greywater of neighbouring countries [218]. Further, the COD and TSS parameters exceeded those of other industries such as dairy mills or pineapple production [219, 220, 221]. Three sources of greywater were sampled: hand washing in a sink, kitchen water-use, and laundry water-use. The effluent parameters from these sources included a COD of 35-70,032 mg/l; a pH of 3-10; an Electrical Conductivity of 209-6890; a TSS of 168-9280 mg/l; a NH4- reading of 0-504.5 mg/l; a PO_4^{3-} reading of 0-82.8 mg/l, and a Biological Oxygen Demand (BOD) reading of 0-3358 mg/l. In first four households in these Figures 4-2A, 4-2B and Table 4-2 show higher OM compared with the rest. Organic sources in the hand washing or in the laundry can be various. Diaper washing is common in Mongolia, furthermore skin particles, hair, fats (from body and other origin) can be presented in both hand washing and laundry effluent. As the local greywater constitution heavily fluctuates on a daily basis, high organic loading from individual households can be related to specific user patterns during the sampling period (e.g. heavy oily cooking before sampling day). The low values from houses 13, 14, 16 and 17 could be explained respectively. In addition these households might have had individual access to groundwater (by e.g. private boreholes (not confirmed though), which could have led to dilution and resulting lower concentration. The disparities between COD and BOD could be related to the way of sampling. The laboratory analysis was conducted under ISO standards respectively effluent results can be regarded as scientifically firm. However, it is possible that separate streams might have been mixed up (during sampling or transport) prior to analysis, leading to high values from laundry or hand washing in individual cases. The concentration of the chemical parameters in greywater was aggravated by low water consumption in Ger areas and excessive and intensive usage of chemical detergents [217].





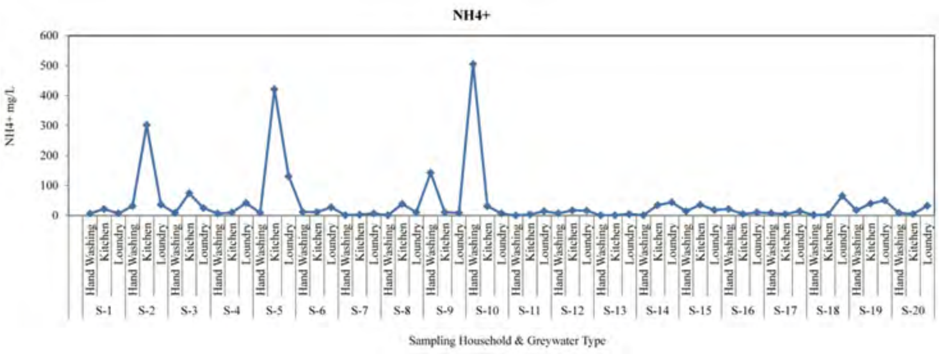
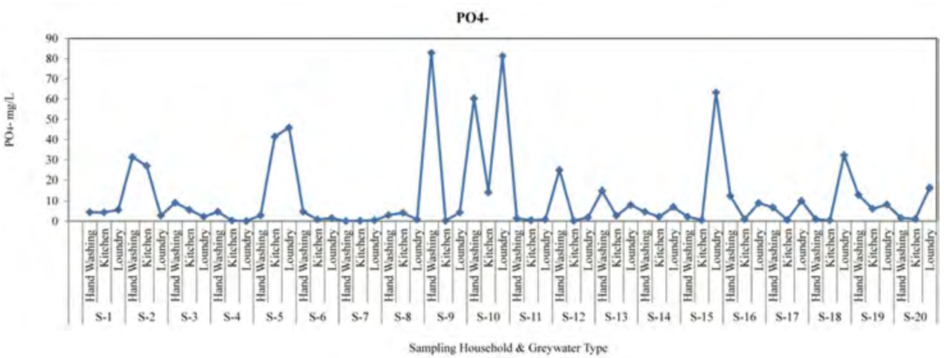
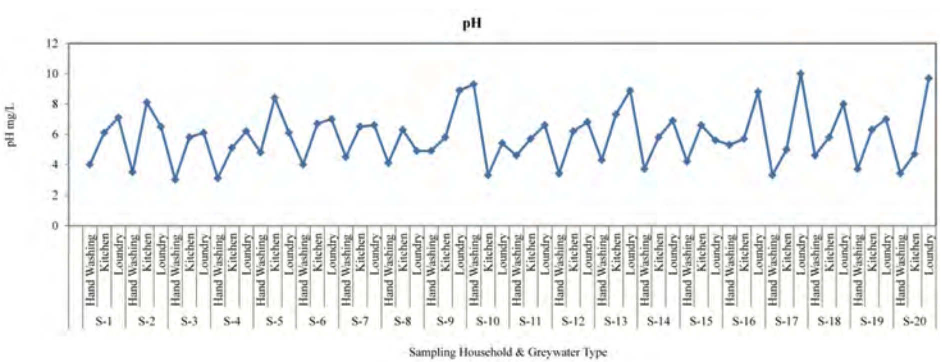


FIGURE 4-2A CHEMICAL PARAMETERS OF GREYWATER. [217]





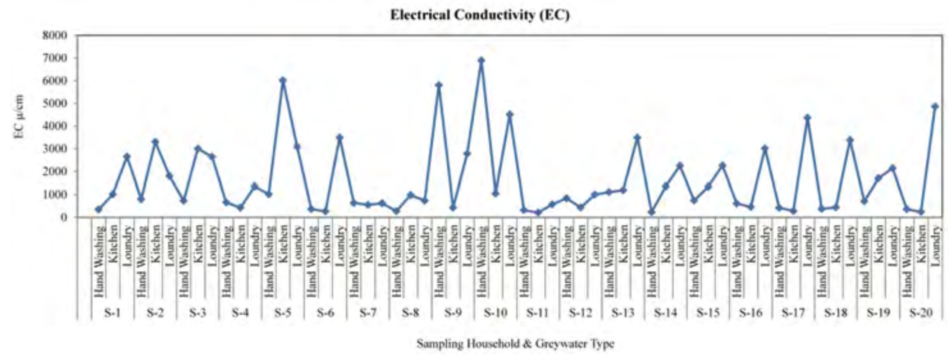


FIGURE 4-2B CHEMICAL PARAMETERS OF GREYWATER. [217]

4.1.3 FACTORS THAT INFLUENCE ON GREYWATER

The results from KAP survey among the residents of Ger areas confirms that over 90% households practice the intensive use of detergents for washing their cloths, dishes and other utensils. This non-point source of pollution may increase the potential risks of both underground and surface water contamination which leads to possible health hazards in the Ger areas of Ulaanbaatar [222, 41]. Moreover, this practice may threaten the water supply security (Wu and Chen 2013) in the study area. Limited water consumption (8 l/person/d during winter), same water usage for different purposes, higher/intensive usage of chemical detergents, diet and cooking manners that contain much fat, milk and oil, and modern lifestyle might be the major factors of this high concentration of greywater parameters in the Ger area. Some of these factors were also considered by Ghaitidak & Yadav (2013) [216] as highly influential on the characteristics of greywater.

Customer market survey proofed that in Mongolia the major products of soap and detergent industry include soaps, laundry detergents, dishwashing detergents, household-cleaning products, hair cleaning products, and toothpaste. Laundry detergents account for 40% of the overall market, while soap accounts for 20%, and dishwashing detergent for 15%. Laundry detergents come in powder as well as liquid form, and may contain bleach additives or color brighteners. Dishwashing detergents come in powder, liquid, gel and tablet forms. Soap comes in bars or liquid forms. These characteristics of chemical washing products may have great influence on the high value of chemical characteristics of greywater.

Currently the Mongolian government does not have rules or regulations in place that require listing ingredients of detergents on the label of the products. But authorities that could take a lead in this field are already in place, among these the General Agency for Specialized Inspection, the Centre of Standardization and Measurement, the Unfair Competition Regulatory Authority, the NGO Consumer Foundation, and the Mongolia Customs Agency.

The influence of technology on behavioral change is slow in traditionally nomadic societies. Most people reside in Yurts (felt tents) [223] without connection to water supply, sewerage or any sanitation system. In the Ger areas, each conglomeration is comprised of a combination of families belonging to a specific 'kin' group (or clan) representing a particular village. Normally, this family clan consists of between two to four brothers and their families. Upon marriage, each male member of the family receives his own Ger which increases the number of Gers within a single compound until one family moves away from the compound. Movement from the family compound is often due to overpopulation within the household. As a result, the practice of greywater production and disposal by new residents in the Ger follows these patterns of family movement. Such practices may influence greywater production and its technological replication processes.

Due to their traditionally nomadic culture, the Ger area residents have no historic or cultural attitude to on-site or off-site waste and greywater management. As they live on small urban compounds, they are now confronted with their own residual materials from daily life which they were previously not accustomed to living on open pastures. Among other aspects, this contributes to uncomfortable living conditions. As there is no sewerage system in the Ger areas, inhabitants dig their own pit latrine toilets. Being sedentary in the more urban setting, they depend on animals rather than crop production. Although more people continue to migrate to the urban and peri-urban settings, most of the pastoral nomads retain their food habits and lifestyles. Consumption of other liquids (e.g. milk tea, fermented milk, horse milk) in place of water is highly practiced in nomadic societies. The consumption rate of these liquids is much higher during the longer winter than the shorter summers. Lesser consumption of water due to the difficulty of water collection, and excess fuel consumption from boiling drinking water results in lower greywater production. In order to increase water use efficiency, households use the kitchen greywater to feed dogs, do laundry and for floor cleaning. Only water which was used for personal hygiene is dumped directly. Mongolian style cooking uses much fat and milk. The food intake of most herders is comprised primarily of meat rather than vegetables. The high usage of chemical detergent is becoming increasingly common over the past decade [224]. Table 4-3 shows the types of chemicals used by residents in the Ger areas.

TABLE 4-3 CHEMICAL DETERGENTS USED IN THE GER AREAS.

<table>
<tr><th>PERSONAL CLEANING PRODUCTS</th><th>LAUNDRY CLEANING PRODUCTS</th><th>DISHWASHING PRODUCTS</th><th>HOUSEHOLD CLEANING PRODUCTS</th></tr>
<tr><td>Hand soaps</td><td rowspan="4">Detergent powder</td><td rowspan="7">Dishwashing liquid soap</td><td rowspan="4">All kinds of cleaners</td></tr>
<tr><td>SKIN CLEANING PRODUCTS:</td></tr>
<tr><td>Bath foam</td></tr>
<tr><td>Shower gel</td></tr>
<tr><td>HAIR CLEANING PRODUCTS:</td><td rowspan="3">Fabric softener</td><td rowspan="3">Window/glass cleaners</td></tr>
<tr><td>Shampoos</td></tr>
<tr><td>Conditioner</td></tr>
</table>

(SOURCE [224])

4.1.4 GREENHOUSE GREYWATER TREATMENT UNIT

CHARACTERISTICS OF INFLUENT

The influent of the current GH-GWTU was also analyzed and found to have higher values for different chemical parameters (Table 4-4). In most of the samples, these parameters were higher than industrial wastewater from phenol formaldehyde resin manufacturing, oil refinery [220] and even wastewater effluent from slaughterhouses [219]. The major sources of phosphorus in the influent derive from non-degradable chemical detergents and shampoos used by households [225].

TABLE 4-4 FLUCTUATION AND CHARACTERISTICS OF INFLUENT.

WEEK	TSS	COD	NH_4	NO_2	NO_3	PO_4	*E. coli* 10^5 CFU/100 mL
1	626	1929.6	215.3	0.166	0.25	7.964	0.81
2	1484	2653.2	122.14	1.133	3.04	7.04	0.57
3	840	1640	147.5	0.317	3.79	12.276	0.75
4	64	1302.5	148.6	0.34	2.78	7.854	0.57
5	122	385.9	1.76	0.374	1.64	8.76	0.375
6	330	4824	27.89	0.546	4.87	5.86	0.65
7	290	1785	48.36	0.49	1.64	4.08	0.43
8	1186	1254	328.6	0.162	13.6	6.48	0.45

PERFORMANCE GH-GWTU

The overall performance of the GH-GWTU is satisfactory. The mechanisms of the systems are physically and biologically based. Physical processes are simple (filtration, sedimentation, flotation). The majority of pollutants are assumed to be organically bound in the sludge evolving from the treatment processes [203]. The chemical analysis results indicate that the maximum removal rate of the system is over 90% of COD, NH_4^+, NO_3^-, NO_2^-, P and TSS. This removal rate is much higher than the rate shown in previous studies [226]. Figure 4-3 (A-F) show the graphical presentation of the system performance of the GH-GWTU. The average TSS of the influent ranged from 66-1484 mg/l while the treated samples ranged between 44-290 mg/l. The maximum removal rate of TSS in the treated greywater was 92%. This rate is much higher than the results reported by Chaillou et al. (2011) [226] and Friedler et al., (2005) [227], however the water does not meet the Chinese discharge standard of pollutants for municipal wastewater treatment plants [206]. The COD concentration of influent ranged from 385.9-4824 mg/l, while the effluent ranged from 139 to 820 mg/l. COD is not directly removed in the system, but mostly stored/accumulated in the sediments. However the sludge is removed frequently from the system, leading to an actual removal of COD on a regular basis. This can be explained by the high concentration and fluctuation of produced greywater composition in different days. Although the maximum removal rate of COD was 94% and is higher than that reported by Friedler et al. (2005) [227], the effluent standard still exceeds the suggested guidelines of comparable neighbours such as China. In relation to ammonium removal, the maximum removal rate was 98%. This rate is again higher than those reported in previous studies [228]. Fluctuation of some effluent samples can be seen as a result of the variation of greywater production and the difference of retention time between different days. As no guidelines exist for practicing greywater treatment and reuse in Mongolia, the guidelines of neighbouring countries can be followed due to some similar geographical and climatic conditions. The concentration of ammonium in most of the effluent samples meets the GB Chinese discharge standard of pollutants for municipal wastewater treatment plants [206]. Accordingly, the treated effluent can be discharged to the designated places in reducing the risk and hazards to both human and environmental health. The performance of the system on P removal is higher than most of the other parameters with a maximum of 98%. The effluent concentration ranges from 0.188-0.924 mg/l and is more efficient than the results of other studies [229]. The performance of the system was not as stable with respect to P removal. The concentration of P in the effluent was <1 mg/l and met the GB Chinese discharge standard (B grade) of pollutants for the effluent of municipal wastewater treatment plants [206]. No temperature effect was found on the overall treatment processes. However, the greenhouse may extend the treatment period up to end of November which may reduce the significant amount for storing greywater during the winter.

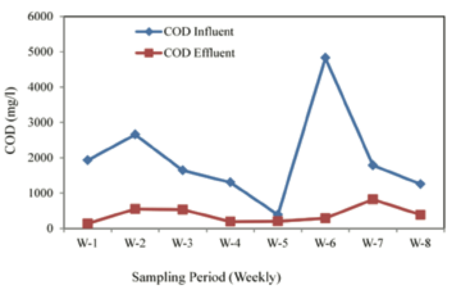


FIGURE 4-3A COD REMOVAL RATE (SAMPLING SEP-OCT 2013)

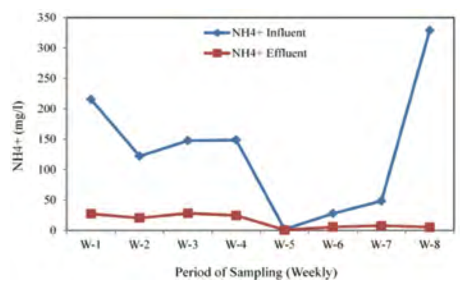


FIGURE 4-3B NH_4^+ REMOVAL RATE (SAMPLING SEP-OCT 2013)

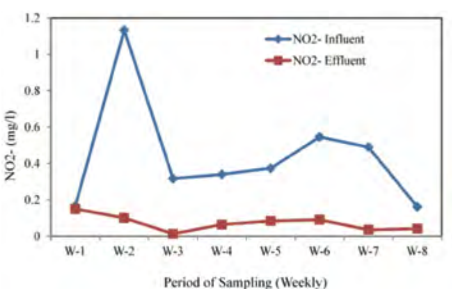


FIGURE 4-3C NO_2^- REMOVAL RATE (SAMPLING SEP-OCT 2013)

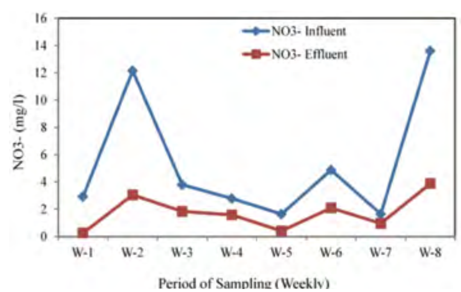


FIGURE 4-3D NO_3^- REMOVAL RATE (SAMPLING SEP-OCT 2013)

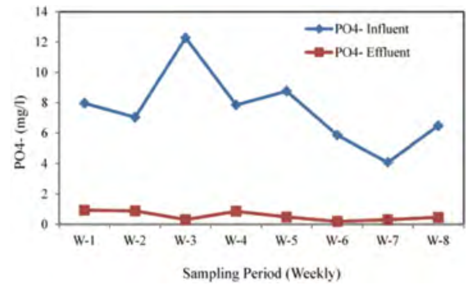


FIGURE 4-3E PO_4^{3-} REMOVAL RATE (SAMPLING SEP-OCT 2013)

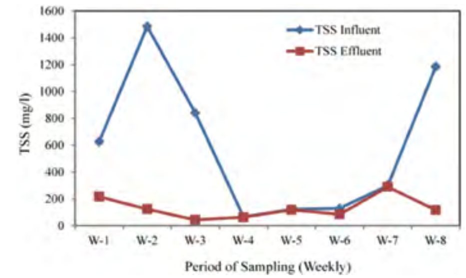


FIGURE 4-3F TSS REMOVAL RATE (SAMPLING SEP-OCT 2013)

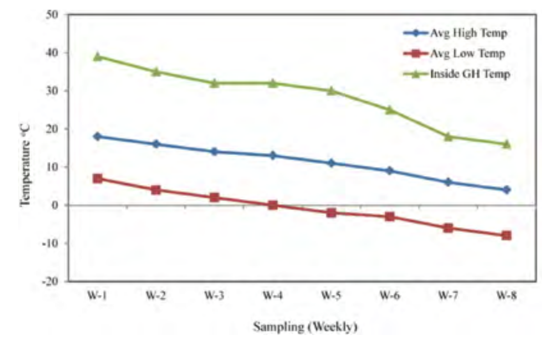


FIGURE 4-3G AVERAGE TEMPERATURE INSIDE AND OUTSIDE GREENHOUSE DURING SAMPLING (SEP-OCT 2013)

N and P are biologically removed. Parts of total N (also NH_4^+) is supposedly reduced in the biofilms (aerobic and anaerobic layers covering filter media), where, as result of denitrification (also in anaerobic part of the biofilm) N is transformed to N_2 gases out. Biofilms tend to consist of an aerobic and anaerobic layer. The aerobic layer could be established with the oxygen entering the system. However, O_2 was not analyzed in the samples, only assumptions can be made. Even though the process of denitrification might not be fully completed, some transformation is assumed to take place leading to N reduction. A large fraction of N are supposedly taken up organically by various OM and bounded in the sludge. P is assumed to be removed by biological phosphate elimination, thus, by bacteria (in the biofilm) that take up more P that they need for growth. As with parts of N, P remains in the sludge. High retention times could have led to high removal rates and stable effluent concentration. In this greywater treatment system, Hydraulic Retention Time (HRT) was relatively longer comparing to large scale treatment system. Thus, the hydraulic load was lower, and surface-aeration may play an important role, which could promote the nitrification process. At the initial stage, anammox process could also happen with high ammonium contents (Jetten et al., 2001) [230]. Slow sand filter could form aerobic biofilm layer and nitrification bacteria could grow in the biofilm, which was also helpful for nitrification process.

Uncontrolled land discharge of treated wastewater or unplanned household greywater discharge can cause nitrate contamination in surface, groundwater resources and soils. Such contamination can create hazards for infants and pregnant women through direct, indirect or cross-contamination of drinking water sources [231]. Parslow (1997) [232] reported that the risk of childhood diabetes increased from a baseline of 1.00 at nitrate concentrations below 3.22 mg/l to 1.27 at concentrations of more than 14.85 mg/l. The updated system has achieved up to 91% removal rate of nitrate, giving a much higher result than previous studies, and meets the effluent quality guidelines for reclaimed water in other countries (e.g. Jordan) [233, 234]. The influent quality of the nitrite ranged from 0.162-1.133 mg/l, which is higher than the influent quality of 0.03-0.30 mg/l reported by Chang et al. (2013) [235]. The maximum nitrate removal rate of up to 96% was achieved and meets the Chinese Municipal discharge standard to the environment.

The greywater also contains the greater number of *E. coli* bacteria in the samples (Figure 4-4). Although the removal rate of *E. coli* has a maximum rate of 88.4%, the effluent quality does not meet the Chinese discharge standard to the environment. An effective and appropriate disinfection process and may be an additional slow sand filter might be required before discharging this treated water to the environment or reusing purposes.

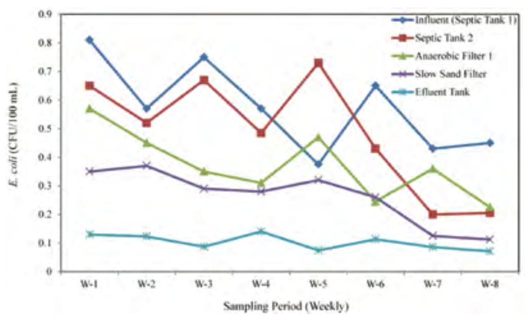


FIGURE 4-4 *E. COLI* REMOVAL (CFU 10^5 /100 ML) IN EACH STEP OF THE GH-GWTU.

The fluctuation of the composition of the influent may be due to the different composition of the greywater across different days, which likely influences the uniform test results of the effluent. The factors leading to a high concentration of effluents within greywater refer to the re-use of water for different purposes the high content of fats and grease in the water being re-used. The strong nomadic traditions of consuming products with high fat content is exacerbating this effect. These consumption habits may be having an influence on the high concentration of greywater. A post-treatment of effluent from the system is needed for some parameters in order to meet the norms of various field applications for reuse. It is suggested to change the sand of slow sand filter after certain period to keep the system, running and improve the efficiency.

4.1.5 ICE-BLOCK GREYWATER TREATMENT UNIT PERFORMANCE OF IB-GWTU

The laboratory test results indicated that the system performed very well in terms of different chemical parameters (Figure 4-5 A-F). Among the parameters, COD removal rate ranged from 98-100% was achieved which was higher than the values reported in most of the studies [236, 237, 238, 239]. The COD concentration of the influent varies from 66.9-808.4 mg/l, while effluent values ranged from 0-19.2 mg/l. The effluent meets the standard of China Class 1 (A grade) of municipal wastewater discharge to the environment [206]. It also meets standards to apply to the restricted irrigation in Israel [203]. The concentrations of TSS in the influent ranged from 30.4-375 mg/l, while the greywater from the outlet ranged from 2.5 to 11.2 mg/l. The maximum removal rate of 97% was achieved which meets the standard of water reuse to garden in Portugal [240]. The effluent meets the standard of China Class 1 (A grade) of municipal wastewater discharge to the environment [206]. NH4 values from influent range from 5.4-14.5 mg/l, whereas the treated samples lie in the range of 0.1-0.32 mg/l. Maximum removal with 99% was achieved. Mean effluent concentration is 0.2 mg/l which is lower than the threshold values from Israel and India for unrestricted irrigation. The effluent meets the standard of China Class 1 (A grade) of municipal wastewater discharge to the environment [206]. Nitrite values in of the influent range between 0.017 and 0.363 mg/l, the effluent concentration range from 0.004-0.04 mg/l. The maximum removal rate of 97% was achieved. The mean effluent concentration remains very low with 0.02 mg/l. NO_2^- requirements are not specified by the regulations provided in this study. The TN threshold value for effluents from wastewater treatment units in Germany is 18 mg/l [241]. Influent values of PO_4^{3-} range from 0.147-0.492 mg/l, while effluent concentrations lie between 0.055-0.094 mg/l. In terms of PO_4^{3-} 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 [203]. Figure 4-5 shows the higher value of the parameters in the week 3 which may be due to high usesage of chemical detergents and the higher content of fats and oil from the kitchen. It can be also explained the low production of greywater during the week which may cause the higher concentration of the the chemical and biological parameters.

E. coli values from influent varied from 130,000 to 2,100,000 CFU/100ml for, the treated samples ranged 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 threshold values are 100,000 CFU/100ml in the case of limited exposure or if regrowth is likely.

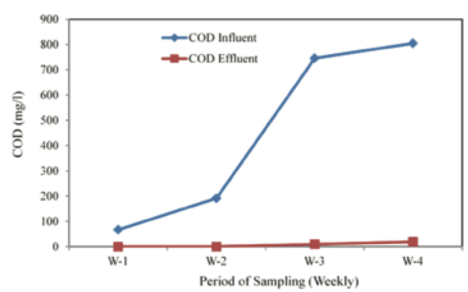


FIGURE 4-5A COD REMOVAL RATE (SAMPLING OCTOBER 2014)

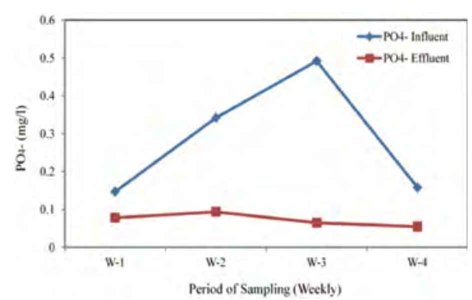


FIGURE 4-5B PO_4^{3-} REMOVAL RATE (SAMPLING OCTOBER 2014)

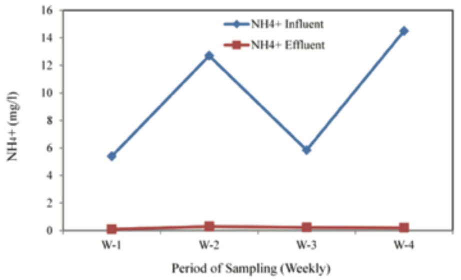


FIGURE 4-5C NH_4^+ REMOVAL RATE (SAMPLING OCTOBER 2014)

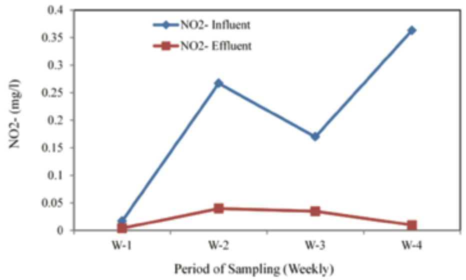


FIGURE 4-5D NO_2^- REMOVAL RATE (SAMPLING OCTOBER 2014)

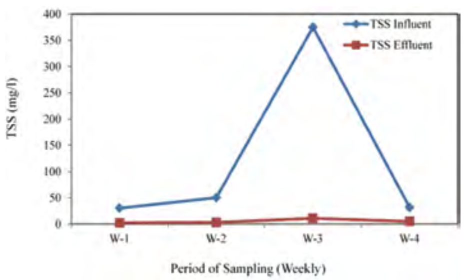


FIGURE 4-5E TSS REMOVAL RATE (SAMPLING OCTOBER 2014)

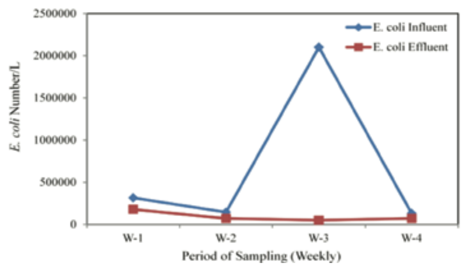


FIGURE 4-5F *E. COLI* REMOVAL RATE (SAMPLING OCTOBER 2014)

The overall performance of the system provided very satisfying results. The maximum removal rate of the whole system is over 90%. 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. However, *E.coli* concentration is lower than the requirements for restricted irrigation by the WHO. Even in comparison to the theoretic treatment potential the IB-GWTU provided higher mean effluent concentrations for all parameters except TSS and *E.coli*. This system and the concept is proved to be feasible in the cold climate regions and also in a condition where people produce less greywater with high concentration of both chemical and biological agents. It is recommended to test this system within a greenhouse compound to increase the treatment period and efficiency as tested previously in different system.

4.1.6 GREYWATER-BORNE HAZARDS

The present study has emphasized the high concentration of chemical and biological agents in greywater which may have the potential to cause health and environmental hazards and may increase vulnerability for populations in Ger areas. Untreated discharge of greywater in the soil of the Ger compounds can enhance the movement of chemicals such as phosphorus to the environment and cause contamination of soil, surface and groundwater. Currently, a conventional sewage system may not be feasible for collecting only greywater from households due to high economic costs, short construction periods, harsh climatic conditions and the lack of planning and standardization of infrastructures in the Ger areas. Therefore treatment of greywater with economically feasible, socially acceptable, and technically suitable methods is needed to remove the various chemicals and pathogens from the greywater in the Ger areas before discharge to the environment. In the current study, a high concentration of *E. coli* bacteria was found in the greywater with potential sources of fecal contaminations deriving from the laundry, kitchen sinks, and dishwashing water comprised of fatty fermented milks, milk tea, and meat. The discharge of household greywater with high concentrations of phosphate and other chemicals released to the environment can also create environmental and health hazards for the residents in the study area [242]. In this manner, people may become more vulnerable to greywater-borne risks and diseases. Due to a lack of legislation on detergent imports and low levels of public awareness related to detergent usage, phosphorus content is high in the greywater produced resulting in both health and environmental risks [242, 243].

4.2 HUMAN FECES MANAGEMENT AND TREATMENT

4.2.1 PROBLEMS AND ACTIONS

Focus group discussions with the stakeholders including ACF internal officers revealed a range of problems faced at the beginning of the project and ACF aimed to solve those problems gradually. The sanitary problems in the study area include for instance very poorly sealed pit latrines, bad odor, poor ventilated systems in the pit latrines, rocky ground and high water table, difficulty in digging pits, extreme winter cold climate, limited space to shift new pit latrines, complaints from neighbors, waterborne diseases, filling the pit latrines by rain water, waste of resources. ACF started to test various technological and non-technical options to solve these problems holistically or integrated ways. The initial aims of the programs were to improve the pit latrines by different awareness activities and school sanitation programs, development of emptyable toilets such as ventilated improved pit latrines and raised toilets due to the high water table, introduction of sustainable sanitation system (SSS) including resource reuse and nutrient recycling oriented system, treatment of fecal matters through composting, and other potential actions towards resource recovery, better human and environmental health.

4.2.2 HISTORY AND EXISTING SYSTEM

40 eco-toilets which aid in recovering resources were constructed by GIZ in 2006 within Ger areas of Ulaanbaatar. A rapid appraisal in 2008 concluded that in the majority of cases, the installed ecological sanitation (ecosan) system was not accepted by Mongolian users due to several factors such as technical drawbacks, lack of disposal collected from the toilets, high construction costs and no user willingness to pay for the toilets [37].

However, the implementation of the system did not focus on the entire SSS, but rather than only on the toilet component. The emptying service was very limited and collection of fecal matters from these toilets was not frequent. As a result, the implementation of the eco-toilets was discontinued. The present study refers to SSS toilets as the former ecological sanitation (or ecosan) approach. Indeed, ecosan is much more than a certain toilet type. In the 2008 report ecosan was referred to as only UDDT (urine diversion dry toilet) whereas the term ecosan refers to any recycling aspect of any wastewater products including compost produced from feces or urine stored and sanitized and subsequently used as liquid fertilizer. However, this is only one component of ecosan within a gamut of sustainable sanitation solutions. After gathering lessons from the past project in 2009, ACF Mongolia has adopted the challenges and started the ecological sanitation project in the study area towards closing the loop of the entire sanitation system (Figure 4-6).

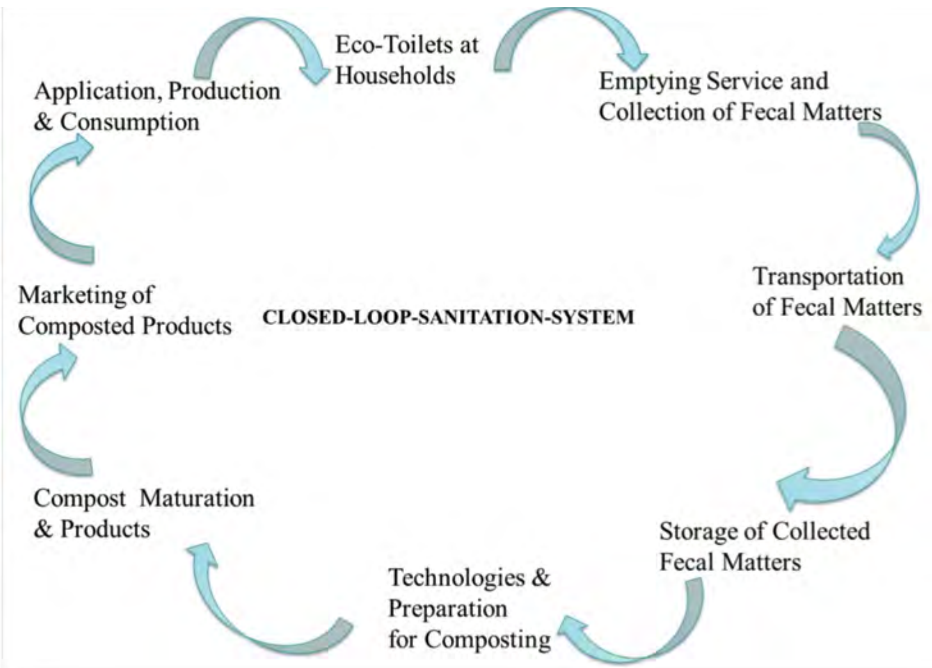


FIGURE 4-6 STEPS OF CLOSED-LOOP-SANITATION-SYSTEM.

4.2.3 SS TOILETS

The construction of SSS toilets around the Ger areas was the part of ACF WASH programs. Several toilet models such as: Urine diverting dry toilet (UDDT); Ventilated Improved Pit (VIP) and Raised UDDT; Bucket dry toilet; Single and Double vault solar toilet, Zip-Zap toilet were constructed and piloted by ACF since 2009 [217].

The concept of SSS and the toilets were fully accepted as considers human wastes (feces and urine) as resources to be conserved and recycled to increase soil fertility and water holding capacity rather than as wastes to be discarded. People were easily understood the reuse and recycling concept under SSS due to the awareness programs and other activities in the intervention areas. In addition, the fecal matters are collected from the toilets frequently and there was no bad odor and flies have been experienced by the Ger residents. Digging pit for pit latrines is a difficult task due to the specific hydromorphic characteristics, particularly the mountainous terrain of the study area also promoted the choice the SSS toilet models. Therefore, these are the major drivers towards the acceptance of the models of SSS toilets by the Ger residents, as majority of the toilets such as raised UDDTs do not need pit to dig and for their installations. In addition, the Zip-Zap toilet (the toilet which can be moved during the emptying services) needs shallow deep to dig for setting bucket in it. The current systems included 120 toilets in the study area for SSS. More recently, 250 additional toilets were constructed by ACF to up scale the system towards sustainability in the field of sanitation and to improve the technological ladder (Figure 4-7) in the areas. Field investigations have indicated a range of advantages and shortcomings of the SSS toilet models (Table 4-5).

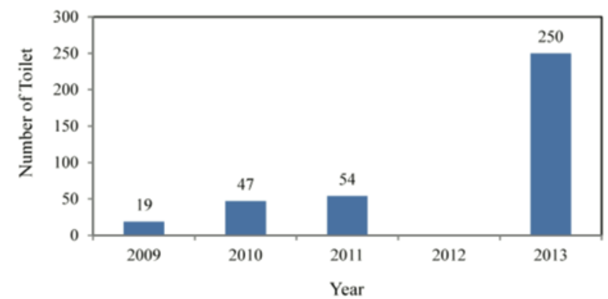


FIGURE 4-7 NUMBER OF SS TOILETS CONSTRUCTED DURING THE PERIOD OF 2009 AND 2013.

Following are the major types of toilets and their merits and shortcomings based on the field investigations:

Single and double vault solar toilet/UDDT

These toilet types were introduced in 2009 at the beginning of the ACF WASH programs to test the feasibility and to improve the existing toilet system in the intervention areas. Only 19 toilets were installed to learn the lessons and for further technical improvement and increase the awareness of the Ger residents. VIP latrines were installed to improve the existing unimproved and unhygienic pit latrines in the area. Double vault solar toilets were installed to alternatively use the chamber when the one filled. In addition, the emptying service and collection can be carried in low frequency. There were some challenges on technical and maintenance encountered such as difficulty in collection, absence of container inside the chamber, bad odor and flies.

Raised UDDT

These types of toilets (Figure 4-8) were installed in 2010 and 2011 and the main idea was to prevent both surface and ground water contamination especially areas with high water table, flooded and hard rocks. The feces without urine fall directly into a bucket inside the chamber, with the addition of sawdust after every defecation to reduce smell and enhance dryness of the feces. After period of time (3 months), the bucket is removed and transported to semi centralized composting facility for proper hygeinization. This type of toilet involves no movement of superstructure; rather, the steel bucket containing feces is accessed behind the structure during emptying service. Ventilation pipe with cap cover is attached above the roof and there is availability of staircase with handle for accessibility. Plastic buckets with handles were inserted inside the recent raised UDDTs instead of steel bucket to avoid corrosion and for easy collection and emptying services.

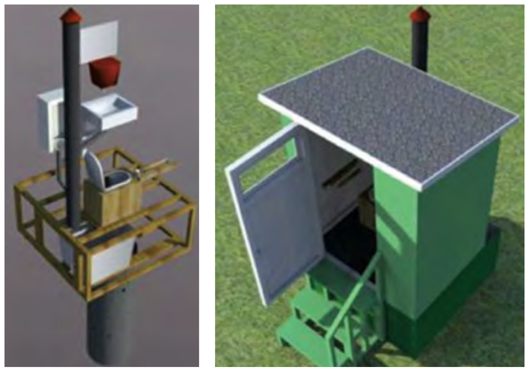


FIGURE 4-8 RAISED URINE DIVERSION DRY TOILET.

There were some problems revealed from the respondents during the interviews with the raised UDDT users. Majority of the respondents experienced heat due the iron sheet used for top cover on the toilets. The hole for urine diversion was too small, therefore, clogging occurs. The diameters of urinal pipes are very small and get frozen during winter, which consequently leads to blockage. None of the toilets has sucking turbine vent; rather, they have rain cover on the ventilation pipe. Rain and flies get into the toilets through the ventilation pipes and through uncovered spaces. Very recent design of raised UDDTs which have been installed in 2013 consisted a large device for urine diversion to solve the urinal clogging.

ZIP-ZAP toilet

Zip-Zap toilet (Figure 4-9) is another form of UDDT that involves digging pit in the ground and placing steel bucket in it to avoid ground water contamination. During empty service, the toilet superstructure has to be moved forward in order to access the bucket containing feces. A total of 22 toilets were installed during the period of 2010 and 2011 to assess the technical feasibility and up scaling capability. This type of toilet has easy accessibility for old people and small children because of no staircase. It was less expensive in terms of construction cost as to compare with Raised UDDT. Urine was diverted and soil in-filtered and sawdust was added to feces to reduce moisture content, flies and odor.

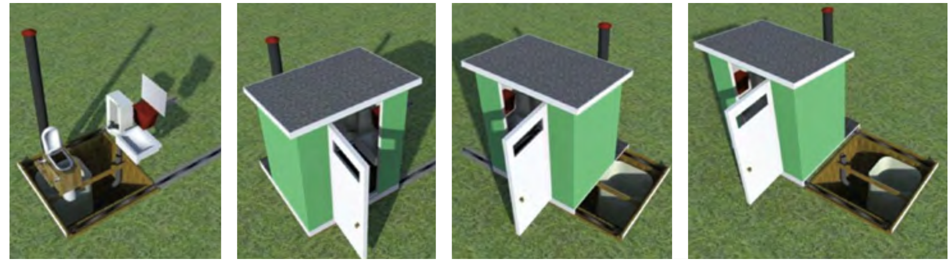


FIGURE 4-9 SKETCHES OF ZIP-ZAP TOILET.

There were a range problems faced by the users. There were no open-able windows for cross ventilation especially during summer period. The toilet was not feasible at rocky and high water table areas. Digging of hole is too difficult due to some rocks beneath the soil. There are difficulties faced during movement of toilet such as: weight of the toilet; sands obstruction; no lubrication done of iron wheel and rail; therefore rusting of the rail. During raining seasons, water flows into the pit, thereby increasing the odor of the toilet. Emptying service proves difficult during winter due to freezing of the water and feces. Urine was not collected, thereby leads to possible ground water contamination, as the pit was not lined. Some households were using the urine seepage well for grey water disposal.

TABLE 4-5 ACF SS TOILETS, THEIR ADVANTAGES AND SHORTCOMINGS.

TYPE OF TOILET/ (YEAR OF INSTALLATION)	NO. OF TOILET	ADVANTAGES	SHORTCOMINGS
Bucket dry toilet (2009)*	2	Can be used in the house	No ventilation pipe
		No ground contamination water	No urine diversion
			Potential health risks unless the bucket or containerization system is carefully designed
Raised VIP toilet (2009)*	3	Ventilation pipe	No urine diversion
		Feasible in flooded areas	Squatting during defecation
		Less perceived smell	Groundwater contamination
UDDT (2009)*	5	Urine diversion	Low quality material used for superstructure
		Less groundwater contamination	Small hole for urine diversion
		Sawdust as bulking agent is added to feces to reduce moisture	

TYPE OF TOILET/ (YEAR OF INSTALLATION)	NO. OF TOILET	ADVANTAGES	SHORTCOMINGS
Double vault toilet solar (2009)*	9	It involves solar heating	No urine diversion
		Alternating storage due to two chambers	Squatting during defecation
Raised UDDT (2010)	46	Ventilation pipe is attached	Small hole for urine diversion (clogging occurs)
		Feasible at rocky and high water table areas	No sucking turbine vent
		Presence of windows for cross ventilation	Low quality material used for superstructure
		Toilet seat (pedestal) is available	Small diameter of urinal (clogging occurs during winter)
		Sawdust is added defecation	
Raised UDDT (2011)	33	Large hole for urine diversion	Lack of window for cross ventilation
		Reduction of flies and smell	Swelling and cracking of superstructure
		Transparent glass sealed windows for light reflection	No collection of urine
		Sucking turbine vent is attached	Unscreened ventilation pipes are used
		Emptying service is very easy and convenient	Access difficulties for elderly and small children
Zip-Zap toilet (2010-2011)	22	Easy accessibility for elderly and small children	No open-able window for cross ventilation
		Less expensive when compared with raised eco toilet	Not feasible at rocky and high water table areas
		Requires no water (only for hand washing)	Difficulties are faced during emptying service
			Urine is not collected
TOTAL (2009-2011)	120	THE ABOVE ASSESSMENT WAS BASED ON THESE TOILETS	
Raised UDDT (2013)	250	Newly built toilets	

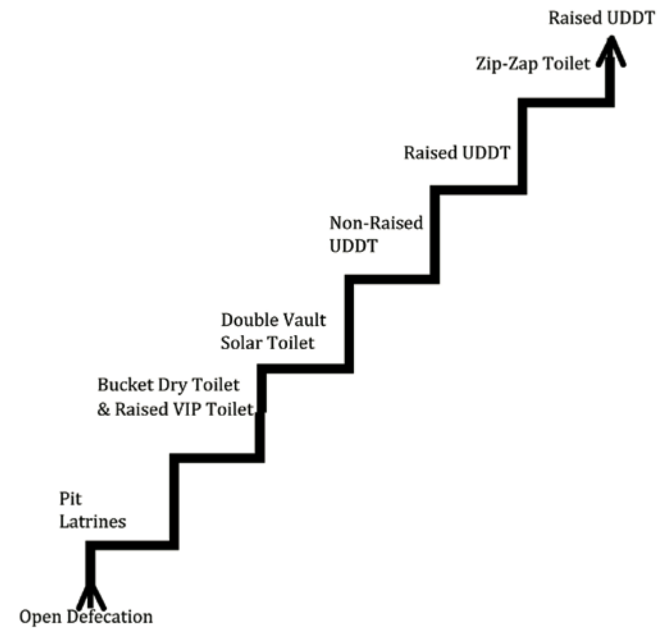


FIGURE 4-10 TECHNOLOGICAL LADDER INCLUDING SS TOILETS IN THE STUDY AREA.

4.2.4 EMPTYING SERVICE SYSTEMS

The emptying service addresses the disadvantages of existing SS toilets. A key principle of the majority of toilets is the urine diverting system. The Urine diverting seat is installed in the toilet cabin and urine is disposed in the urine pit through the urine pipe. Dry feces are collected in the collection bucket with sawdust. As a procedure, the user is requested to sprinkle sawdust in the chamber after defecation. This process not only prevents foul odors but also activates the pre-treatment process, in which a carbon source is provided to bacteria present in the feces. It also has the advantage to reduce the waste volume, as well to avoid the unnecessary mixing of urine and feces, which is generally infectious. The emptying service covers the replacement of the feces collecting buckets from the toilets which have exchangeable buckets inside. The toilets such as VIP do not have the bucket replacement system and external buckets are used for collecting feces from the toilets. The emptying service officers have been trained on emptying services and are aware of personal hygiene and protection in order to avoid pathogens transmission during the services. All the necessary precautions were taken such as protective gadgets, synthetic lotion, and avoidance of food consumption, smoking/drinking or excessive communication during emptying service to prevent transmission of contagious diseases and to protect from air-borne transmissions through fecal-oral-rout. At every three month interval, emptying services are carried out across each household by ACF. The filled buckets are exchanged with clean and empty ones, and transported to the composting site for further hygienization. Despite the above precautions taken by the emptying staff, there are still some shortcomings observed during the service. The shortcomings include traces of feces in the steel/metal bucket, leakage of buckets, buckets with no handles, and unexpected splashing of feces on the ground due to poorly fastened screws or clamps. One of the major problems encountered during the summer is the strong odor during the process of emptying and collection. This problem can be addressed by maintaining the toilets properly and using the bulking materials sufficiently after each defecation. In winter, the feces turned into ice-blocks which become harder to break during the emptying services, but without the problems of foul odors. A recent improvement of emptying buckets includes plastic buckets with handles for easier discarding. The emptying service operators use washable cloths, latex gloves, strong work gloves, boots, and masks with carbon filters. The operators remove their boots when boarding the truck and place them on the truck platform. The staff is provided with required tools (e.g. shovel, crowbar) sometimes used in winter when the feces collecting bucket might stick to the toilet frame or to the urine pipes due to the freezing conditions. After use, the operators store the tools in the dirty tools box placed on the truck platform. Upon arrival at the treatment unit, the staff unloads full buckets from the truck. These are manually emptied into barrels (220 liters) using the shovel and crowbas. The barrels are stored in the bucket storage during winter time. From April treatment of feces through summer composting commences and the collected feces are used for the compost production. After completing the emptying service the truck is cleaned on a daily basis. Currently the emptying service is delivering the service to 120 toilets.

Results from the household survey showed that 90% respondents among the SSS toilet users receive manual emptying services and 5% respondents had the mechanical vacuum tankers for emptying services. Currently no respondents pay for emptying services, as it is executed by ACF Mongolia. However, 77% of the respondents were willing to pay for each emptying service and rest of them were not ready to pay any money, may be due to their low income level. Handing over the whole system to a company might be possible for proper operation and maintenance of the system.

4.2.5 COLLECTION, TRANSPORTATION AND STORAGE

The collection of feces is arranged after completing emptying services by using the small truck run by the emptying officers of ACF Mongolia (Figure 4-11). Transportation of fecal matters to the treatment site requires special consideration due to the rough communication systems in the Ger areas. Fecal matters in the collecting buckets are typically very dry, thus conventional suction pumps cannot be used to suck out the feces from the bucket. Two officers have been manually extracting the feces collecting bucket from the toilets which has been highly labor intensive. They cover the bucket with a lid and move it on the truck platform while replacing the full bucket with an empty bucket in the toilet. The truck can currently be safely optimized to hold 8 buckets. The collected feces are kept in a store-house at the site of treatment/composting during the summer and outside when storage space is lacking during the winter when the temperature is at freezing level. Figure 4-11 shows the emptying services including the collection, transportation and storage at the composting site.

FIGURE 4-11 COLLECTION, TRANSPORTATION AND STORAGE SYSTEM FOR HUMAN FECES.

A pilot field trial (Figure 4-12) conducted by ACF Mongolia in semi-centralized winter composting unit (SC-WCU) shows that during the period of 27 January to 27 February 2012, average low temperature during this period ranged from -32°C to -25°C and average high temperature ranged from -15°C to -7°C.

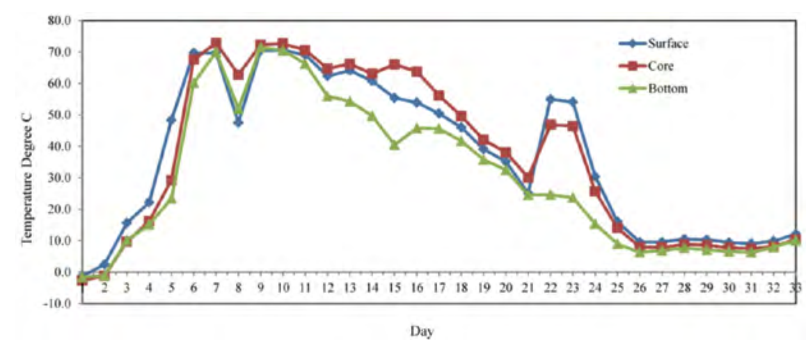


FIGURE 4-12 TEMPERATURE READING OF COMPOSTING IN SC-WCU.
(FIELD DATA FROM 27 JANUARY - 27 FEBRUARY 2012, ACF MONGOLIA)

The average ambient temperature in the facility was over 20ºC whereas the core heap temperature remained >70ºC for over a day and more than 50ºC for 9 days which meet the international standards in terms of temperature and pathogen die-off [215]. There is a sharp decrease of temperature at the day 7 due to the turning of the compost heap. A weekly turning was applied for this composting process to create an enabling environment for the microorganism for decomposition of the organic matters in the pile.

Figure 4-13 (A-D) show the variation of temperature against time period of composting of the current study. For the trials (1-4) in SC-WCU, temperatures were monitored at bottom, core and top of the piles. In these experiments, all the analyses were based on the core temperatures because the bottom temperatures cooled down more rapidly due to aeration that was supplied through the base of the reactors. High temperatures were only maintained at the core and top of the piles and maintained the thermophilic phase. The ambient temperature ranged from 18-24ºC (while the outside average day temperature ranged from 20-24ºC and night from 8-12ºC) which did not have any significant influence on the composting process.

As composting process began, sanitizing/thermophilic phase (>50ºC) was reached within 3 days for Trial 1, 2 and 3, as shown in Figure 4-13 (A-C) respectively, except for Trial 4 that reached the stage after a week (7 days) of composting as shown in Figure 4-13D. Rapid increase in temperature indicates that the available nutrients (carbon and nitrogen) were gradually decomposed and utilized by the microorganisms. In addition, the recipes used in the first three trials contained woodchips or straw, which provided spaces within the piles for evenly distributed aeration.

The maximum temperatures reached in Trial 1, 2, 3 and 4 were 60.6, 63.0, 60.1 and 64.2ºC respectively. Also, the periods of temperatures that were maintained above 55ºC were 11 days, 15 days, 10 days and 16 days as shown respectively. There was no significant difference in the obtained temperatures for the first three trials, whereas, the trial 4 took a complete one week before reaching thermophilic phase, this could be as a result of no bigger particles to create more space for aeration and also, the sawdust used in all the trials was from pine trees that contains high acidity level and lignin contents, which are not easily digestible by the microorganisms. After the active phase of the process ended, microbial activities decreased as a result of decrease in organic matter and weakening of the thermophilic microorganisms; thereby led to gradual decrease in temperatures to the ambient on 36th day.

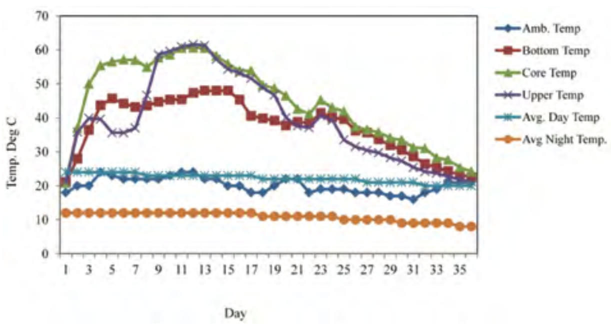


FIGURE 4-13A TEMPERATURE FOR TRIAL 1, FECES WITH SD & ST (JULY-AUG 2013)

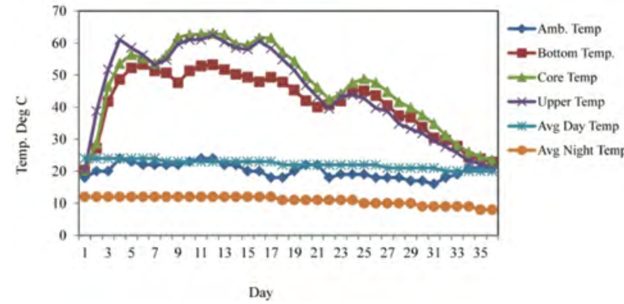


FIGURE 4-13B TEMPERATURE OF TRIAL 2, FECES WITH WC & ST (JULY-AUG 2013)

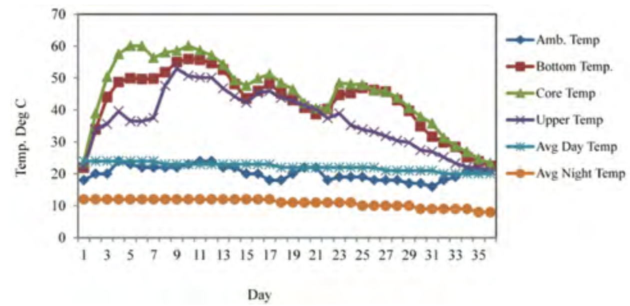


FIGURE 4-13C TEMPERATURE OF TRIAL 3, FECES WITH SD & WC (JULY-AUG 2013)

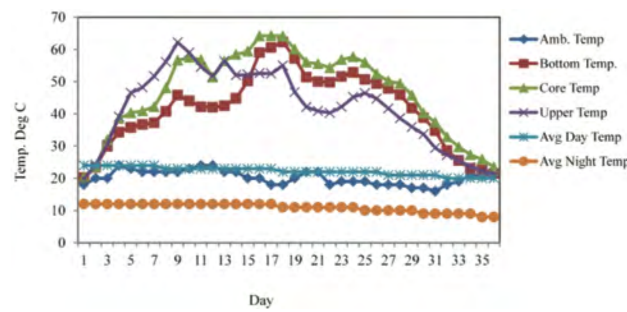


FIGURE 4-13D TEMPERATURE OF TRIAL 4, FECES WITH SD (JULY-AUG 2013)

Turning played a significant role and influenced the temperature variations, for every turning made on weekly basis; there was slight increase in the temperatures. If only the center/core of compost reaches thermophilic phase, turning becomes imperative to ensure all other parts of the piles are well sanitized.

4.2.7 TREATMENT THROUGH COMPOSTING IN SC-GHCU

For the trial 5 in semi-centralized greenhouse composting unit (SC-GHTU), data logger was horizontally placed at the center of the pile and temperatures were monitored. The ambient temperature in the SC-GHCU (Figure 4-14) dropped from 39 to 4ºC as there was corresponding drop in outside temperature from 13 to -19ºC respectively at the end of the trial. At the fourth day of composting, the temperature reached 70ºC; this high temperature could either be influenced by ambient temperature of the greenhouse or the easily digestible carbon source that was added i.e food waste. The temperatures above 55 and 65ºC were maintained for 2 weeks and more than a week respectively, which satisfies all the sanitation requirements including Germany standard. After two weeks of composting with declining temperature, the pile was firstly turned to ensure other parts were exposed to high temperature for proper hygienization. After turning, the temperature rose up back to 65ºC and gradually coming down as outside temperature dropped below 0ºC. The sufficient high temperatures obtained in this trial were in line with observation made by Niwagaba et al. (2009) and Preneta et al. (2013) that mixing of food waste to feces provided easily digestible carbon to the microbes and maintained high temperature for longer period of time [185]. All the trials (1-5) meet the international standard including World Health Organization guidelines [215].

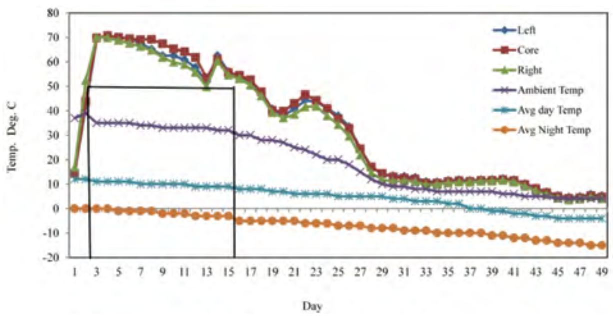


FIGURE 4-14 TEMPERATURE OF TRIAL 5 IN SC-GHCU, FECES WITH SD, ST & FW (SEP-NOV 2013)

pH has also significant influence on the composting process and the product quality. The microbial decomposition began just after the piles were formed, and gradual increase in temperatures was observed. In this study, initial pH dropped from 6.8±0.3 across all the trials (Figure 4-15), this is due to biooxidative action of the microorganisms i.e. formation of volatile fatty acids and carbonic acid, which could lower the pH of the compost, thereby increasing the growth of fungi and degradation of lignocelluloses substance. When this acidification phase is over, and the intermediate metabolites were mineralized i.e degradation of organic acid compounds; pH tends to increase during the thermophilic phase, which leads to increase in ammonia volatilization. In all the trials, the measured pH values across the piles ranges from 5.0 and 9.2. High ammonia volatilization were observed in all the trials, which could be as a result of high concentration of nitrogen (N) contained in Mongolians' urine or weekly turning of the piles, except for trial 5 that was fortnightly turned. Therefore, at the last day (36th day) of the process, the pH values ranged from 6.9-7.7, which shows that the trials' pH at the end of the experiments were within the optimum range of the pH standard both for composting and maturation.

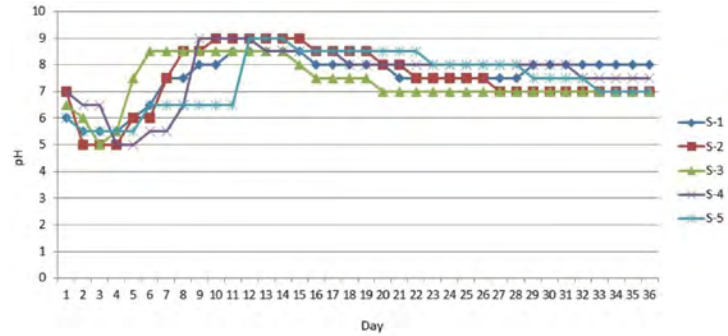


FIGURE 4-15 PH OF ALL TRIALS.

The basic principle of the SC-GHCU is to increase the number of composting frequency and to extend summer composting for more production. A number of 120 eco-toilets, non-sewer/on-site sanitation system, were considered for the development of SC-GHCU and winter composting system. The estimated average production rate of fæces with sawdust from each toilet/household is 600litter/year in the Ger areas which lead to around 70 Mg of fecal matter with sawdust per year from 120 toilets/households. Currently there is a high demand of eco-toilets and ACF has built more 250 toilets during the last summer of 2013 for its scaling up strategies.

4.2.8 COMPOST MATURATION, SAFETY AND RESOURCE RECOVERY

Maturation phase begins when the temperature does not reheat after turning, i.e. when there is steady decrease of compost temperature to the ambient temperature. Several methods have been developed to test for compost phytotoxicity in terms of maturity and stability, so as to reduce the harm caused by immature and poorly stabilized compost. After two months of proper composting process, there is need for the compost to be matured further for at least two months to ensure that the compost is well stabilized and matured. Stabilized compost involves microbial activities in terms of O2 intake and CO2 released, while Matured compost involves the degree level of decomposition and humification. Figure 4-16 & Figure 4-17 show the physical appearance of compost during the maturation both composting units.

FIGURE 4-16 COMPOST MATURATION IN GREENHOUSE (TRIAL 1-4).

FIGURE 4-17 MATURED COMPOST IN SC-GHCU (TRIAL 5)

For the experiment maturation period, another greenhouse structure was built by ACF Mongolia for this process, which helps to keep and extend the maturation period longer, even during the harsh weather condition of -40ºC. After two months of the process, compost piles have been greatly reduced up to 50% of initial volume; then it was taken out, placed inside wood cranes lined with mosquito mesh and placed inside maturation greenhouse. Then, the finished composts were screened/sieved to remove the bigger particles, lumps and any unwanted materials and ready for application.

The period of producing finished compost is not fixed. There is no specific point at which maturing should begin or end. The duration depends on many factors such as: the experience of the operator, feedstock, physicochemical properties of the mixture, composting method and management. Compost could be ready within few weeks or be extended up to two years (cold composting). For instance, long maturation period can provide a comfort zone to cover any potential shortfalls from the composting methodology used and reduces the chance of an immature composted organic product being produced. Immature composted organic products continue to consume oxygen and reduce its availability to plant life. It can also contain a high C:N ratio, high levels of organic acids and other characteristics that can cause damage when used in certain horticultural applications.

Biological test results indicated that there was not a single Salmonella and *E. coli* found in the compost. In addition, there was no indicator bacteria found in the products (e.g. Spinach) produced by fecal compost. Conversely, the compost produced demonstrated qualities in term of productivity. A field experiment jointly conducted by Mongolian State University of Agriculture on the application of ACF fecal compost and mineral fertilizers to produce Spinach indicated that the production by compost was little higher than the production by mineral fertilizers. These results indicated high hygienic status of the compost and the possibility to grow agro-products. It is hoped this opportunity will pique the interests of both government and non-governmental agencies to develop and scale up SSS. Social marketing survey showed that 75% of the interviewed customers were using manure compost produced through vermi-composting. Compared to the demand for chemical fertilizer, the demand of organic compost is higher. The results from social marketing study on compost indicated that 80% of the interviewed partners confirmed their interests in organic compost.. The price of one kg compost was 800-1000 MNT (equivalent to 0.46-0.58 USD). Currently no regulation exists in Mongolia related to fecal composting and its application. ACF and USTB is particularly advocating regulation on the basis of research evidence for fostering support from the government.

Resutls from the nutrient analysis (e.g. Nitrogen, Phosphorus) show that higher P of 1996 mg/kg can be recovered from the sample 5 with SC-GHCU than the other samples and trial. This can be explained as high digestable food waste addition in the composting system and proper decomposition of the materials. On the other hand, 1354.8 mg/kg and 869.9 mg/kg phosphorus can be recovered from the sample 2 and 3 respectively. The phosphorus content in the sample 1 and 4 is lower than the other samples which may be due to the lack of digestable materials in these samples. Table 4-6 shows the TN and TP in the compost samples.

TABLE 4-6 TOTAL NITROGEN AND TOTAL PHOSPHORUS CONTENT IN THE COMPOST.

SAMPLE	TOTAL NITROGEN (%)	TOTAL PHOPHORUS (mg/kg)
1	2.3	154
2	2.21	1354.8
3	2.06	869.9
4	2.35	193.6
5	2.04	1996

In many parts of the world, existence of heavy metal in sewage sludge which is not separated at source is a concern [244]. However, in the current study, Table 4-7, results from heavy metal tests show that composts produced from each trial are safe in terms of heavy metal content and all trials are below the standard limit of the German standard of fecal compost.

TABLE 4-7 RESULTS FROM HEAVY METAL ANALYSIS (MG/KG)

TRIAL	As	Pb	Cd	Cr	Cu
1	0.20	0.72	0.002	1.66	5.70
2	0.19	2.70	0.02	2.07	8.99
3	0.19	4.14	0.11	1.77	7.80
4	0.04	8.05	0.07	0.67	5.14
5	0.17	13.91	0.205	3.96	25.83
German Standart	25	150	3	150	150
Chinese Standart	30	100	3	300	-

4.3 SUB-SUMMARY

Overall removal rate of different parameters of GH-GWTU was satisfactory and a removal rate of over 90% was achieved for all parameters. The results show that GH-GWTU is technically feasible in the study area of Mongolia. Although the removal rate of both chemical and biological agents in the treated water was satisfactory, further advanced or tertiary treatment and disinfection processes are needed to deal with the treated greywater for reuse purposes.

As for the IB-GWTU, the overall performance of the system provided very satisfying results. The maximum removal rate of the whole system is over 90%. All tested parameters except *E. coli* meet standards for unrestricted irrigation as provided.

Results from composting human feces in SC-WCU shows that the temperatures above 55 and 65ºC were maintained for 2 weeks and more than a week respectively, which satisfies all the sanitation requirements including Germany standard.

In the SC-GHCU, over 70ºC of pile temperature was achieved and the average ambient temperature in the facility was over 20ºC maintained. More than 50ºC for 9 days which meet the international standards in terms of temperature and pathogen die-off. Biological test results indicated that there was not a single Salmonella and *E. coli* found in the compost. In addition, there was no indicator bacteria found in the products (e.g. Spinach) produced by fecal compost. Conversely, the compost produced demonstrated qualities in term of productivity.

5 - SOCIAL ACCEPTANCE AND FINANCIAL SOURCES TOWARDS UP SCALING TECHNOLOGIES

5.1 SOCIAL ACCEPTANCE OF GREYWATER TREATMENT AND REUSE

5.1.1 PERCEPTIONS OF USERS AND NON-USERS

The perceptions on greywater treatment and reuse options, except some maintenance and technological issues, were well understood by the 100 percent users of greywater. Based on the physical characteristics of the treated greywater, both GH-GWTU and IB-GWTU are accepted by the users due to their technical simplicity, greywater management system, no bad smell and the good color of treated greywater. However, all the users generally accepted the treated greywater from both units, which indicates that improved models could be scaled up for meeting a part of the water demand in the Ger areas.

KAP survey results show that (Figure 5-1) the perception of greywater reuse among the non-users was well accepted by almost 50 percent of the respondents. They had willingness to reuse the treated greywater and to consume agro-commodities produced with treated greywater.

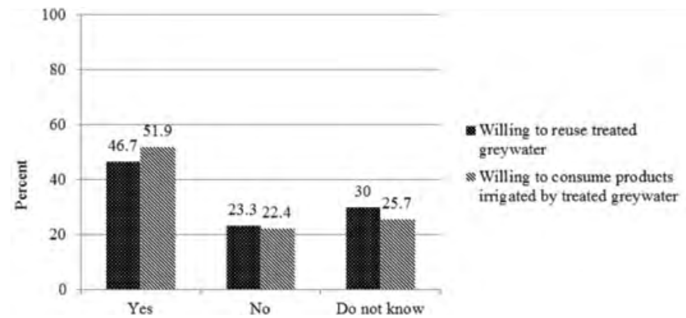


FIGURE 5-1 NON-USERS' WILLING TO REUSE TREATED GREYWATER.

One third of respondents among them do not have any kind of knowledge about the greywater treatment and reuse issue to accept the technology. The rest of the respondents have negative approach to this issue. As the greywater treatment and reuse issue is completely new for the Ger residents, low awareness and knowledge level, and social acceptance is still a challenge for scaling up of the technology. Additionally, the survey results show that most of the respondents had very low awareness level on greywater treatment and reuse issue, organic food consumption, use of bio-degradable detergents and other environmental issues.

5.1.2 CUSTOMER SURVEY RESULTS

The results from the customer survey shown that majority of the respondents (85%) dispose greywater to either pit latrines or soak pit and rest of the respondents dispose to the ground both inside and outside the household compounds. They practiced this due to the lack of other options to dispose greywater and their long terms behavior. The average amount of greywater disposal was 5 liter/person/day. There were a range of problems encountered by the respondents during the disposal of greywater which include full of soak pit and pit latrines, bad odor, flies, freezing during winter which may be hazardous for health, uncomfortable, frequent movement to dispose greywater. A number of respondents (21%) reused water for some purposes such as washing clothes, cleaning house, washing car, cleaning vegetable and irrigating tree at their gardens. Sixty four percent of the respondents were expressed that they are not satisfied with the current system and they were interested to grow vegetables in their compounds by using treated greywater. Figure 5-2 shows that 63% respondents were agreed to treat the greywater before disposal due to sanitary, regulation, health and environmental reasons. Almost half of the respondents have gardens in their compounds which may be a trigger points scaling up the greywater systems in the areas and rest of the respondents may not aware much about the greywater treatment options and its benefits.

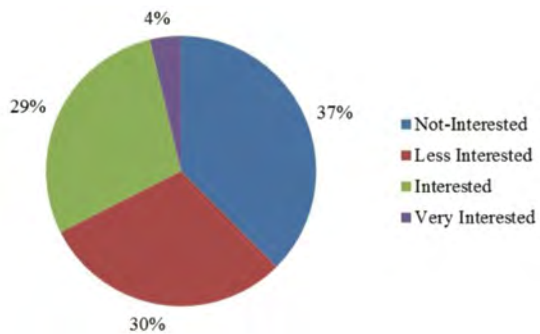


FIGURE 5-2 RESPONDENTS' INTERESTS IN GREYWATER TREATMENT.

Over two third of the respondents were interested to share the installation and maintenance cost with their neighbors to save money. This can be explained that a community scale of greywater system can be scaled up in the areas. Thirty seven percent of the respondents said that they were not interested in greywater treatment and almost two third of them expressed their interests to treat greywater.

5.1.3 OPPORTUNITIES OF GREYWATER TREATMENT AND REUSE

There are a range of opportunities and challenges for treating and reusing greywater in the Mongolian context. Maintenance problems were identified as one of the challenges in both United States and Australia where 60-80% of 'on-site domestic wastewater treatment plants' were not maintained sufficiently [83]. This study also addressed several challenges regarding the period of installation, and maintenance. Local socio-economic and climate conditions pose additional challenges, such as the temperature drop under -40°C, freezing soil down to 3.5m depth during up to 8 month per year, low income people, low level of technical skills for operation and maintenance. These challenges can be overcome by training people and providing simple user guidelines for the system operation and maintenance.

TABLE 5-1 OPPORTUNITIES FOR GREYWATER TREATMENT AND REUSE IN MONGOLIA.

FACTORS	OPPORTUNITIES
Technical	Independent design at household level.
	Tackle future water crisis and meet future water demand to some extent.
	Decentralized so no need to connect with expensive conventional system.
Operation and Maintenance	Human resources development.
	Increased skills, knowledge and awareness.
	Reduce of freshwater use in gardening and other landscaping.
	Low operating cost and affordable.
Social	Current acceptance will enhance future scale up and acceptability of the technology.
Economic	Save the cost of constructing centralized systems.
	Material business.
	Local available materials can be used.
	Possible business options in future.
Institutional	Institutional engagement.
	Networking and coordination.
	Research and development.
Climatic	The extreme temperature can be used as degradation of chemicals and destruction of pathogens.

5.1.4 DIRECTIONS FOR POLICY AND ADVOCACY

There are some major findings from the policy dialogue which can be considered as major challenges. The economic issue is much concerned by government for greywater treatment and reuse options. As long as the price of new water is so cheap reusing greywater will not make economic sense for them in terms of reuse practices. Currently there are no legal regulations in Mongolia on treating/reusing greywater. The greywater treatment infrastructure does not exist in Mongolia. As Mongolia is in transition of development, the country may need lots of things to consider and develop. They may also need expert supports either from NGOs or other stakeholders. Convincing government agencies in many sectors is a challenge including the greywater treatment and ruse. Although economic part is very much important and highly discussed in many forum and they exclude the major parts of the hazards and vulnerability of both health and environment including surface and groundwater contamination due to unplanned discharged of greywater to the environment. Difficulties of water collection by residents due to a range of factors and the contamination issues are also omitted. Proper directions, evidence and advocacy tools on various technological options and social issues can be the major triggers to catalyze government for considering the onsite and decentralized greywater treatment and reuse options in the Ger areas and to formulate relevant regulations and policies on this.

5.2 SOCIAL ACCEPTANCE OF SS TOILETS AND SERVICES

The survey results of the present study indicated that technologies and the services of SSS in the study area are socially accepted by all users of SSS toilets due to some factors. However, 80% of the respondents were not interested to consume the products produced by fecal matter. The results regarding the users' preferences for using SSS toilets in relation to previous pit latrines indicated that 72% of respondents were positively in favor of the benefits. Conversely, the remainder of the respondents (28%) preferred pit latrine to SSS toilet due to some technological shortcomings. Figure 5-3 shows some reasons of using SSS toilets in the Ger areas. Eighty three percent of the respondents expressed three major reasons of using the toilets. However, 62% respondents felt convenience during the winter (Figure 5-4) and rest of the respondents faced some problems to use them such as bad odors, and flies.

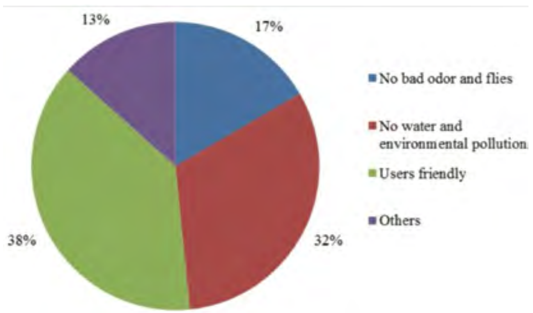


FIGURE 5-3 REASONS OF USING SSS TOILETS.

An impressive percentage of the respondents (73%) were eager to recommend SSS toilets to their neighbors or non-users, provided an improvement is made on the convenience especially during summer. These respondents also stated that, visitors from more rural areas had frequently inquired about how to receive a SSS toilet. Interestingly, nearly all the visited households with SSS toilets had ACF contact numbers in the case of emergencies, emptying services or with demands for obtaining new toilets. Eighty percent of the respondents received training and were involved ACF sanitation programs to maintain the toilets and operate properly. Seventy percent and 10% of respondents clean their toilet cabin in weekly and daily basis respectively. The rest of them clean their toilets when they need to clean. 93% of the respondents do not face any difficulties to maintain the toilets. The results also revealed that all users feel the maintenance costs of their toilets are not expensive. Results from FGD suggested that a majority of the participants accepted the SSS and felt needs to improve the health and environmental conditions of the Ger areas. However, the government officials were much strict or reluctant to apply compost for consumable products due to no policy and suggested to have more discussions and evidence to formulate policy. At this moment, they suggested to applying compost products in non-consumable fields such as horticulture, gardening and other possible filed application.

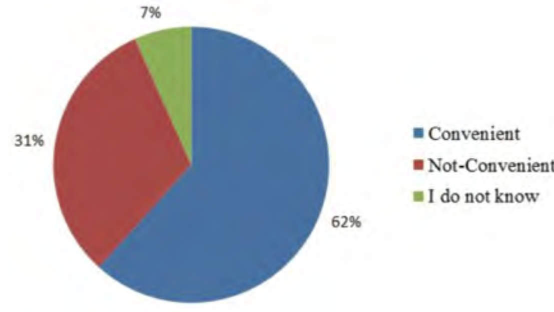


FIGURE 5-4 CONVENIENCE OF USERS DURING THE WINTER.

Although this is not socially acceptable, a winter composting by using the inner environment and materials of traditional 'Ger House' (Figure 5-5) is highly recommended to test the feasibility of the system for composting during the extreme winter condition not only for resource recovery but also for improving health and environmental conditions significantly. Over 0ºC was found beneath the Ger house even during the extreme cold winter in November and it may need to explore in future which might be useful to avoid the cold effect on composting process in the long winter cold country.

FIGURE 5-5 GER HOUSES IN MONGOLIA.
(TAKEN BY UDDIN SMN IN JULY 2013)

5.3 EXPLORING SOURCES OF FINANCES TO SCALE UP TECHNOLOGIES AND SERVICES

Since buying an eco-toilet involves high up-front costs, which pose a barrier to low-income households, several options are explored in order to facilitate covering this high initial investment:

5.3.1 MICRO FINANCING

The results from the interviews among the institutional stakeholders, particularly banks, revealed that micro-credits and loan systems are still new for Mongolia and for the Ger residents of Ulaanbaatar, who have migrated from the countryside. Lending schemes like micro-credit have only been available, especially to low-income families, for the last decade. However, the financial sector has been growing and spreading fast in recent years and there is now a variety of microfinance institutions and a lot of activities in Mongolia.

Key informant interviews with “XacBank” shows that it started as a small non-banking micro-finance institution in the 1990s. It became bank when two micro-financing institutions merged. Since then it has been executed the triple-bottom line approach which focuses people, planet and profit. In the Ger areas of Ulaanbaatar, “XacBank” is involved in traditional microfinance in different ways such as providing conventional small loans to local residents, partnered with an international microfinance-lending organization. The focus of the loans is mainly on small businesses, green lending (e.g. for insulation, energy efficiency) and the newest one, which started in 2012, is for water and sanitation. The amount of loan for sanitation sector is up to 5000 USD.

In the Ger areas, strong majority of residents have access to financial institutions and they are banked. Majority of the people do not have a very developed lending history, but most have some sort of financial relationship with the financial institutions. In generally loan system is something new for Mongolia and for the Ger residents, who are coming in from the countryside and it is something new for this population in general, since Mongolia has only very recently become a capitalist economy. Lending schemes, have only been available, especially to low-income families, for the last 20 years. But the sector has growing largely and quickly and there has been a range of initiatives and variety of microfinance institutions. The collaboration between “XacBank“ and ACF Mongolia has been started for the first time since 2012 in the sanitation sector in Mongolia to explore a range of opportunities to facilitate access to improved sanitation through financing. In addition to this collaboration, they have been looking to work with some local latrine producers to cater the Ger districts to provide more comfortable and cleaner latrines. They have also started to initiate effective collaboration with an international company that has experience in producing materials for latrines and is very interested in producing latrines specific for Mongolian climate and socio-economic settings. At this moment “XacBank“ provides loan for installation of few ventilated improved pit latrines (VIP). They will be sealed so there will be no soil contamination and the waste will be collected by a vacuum tanker. There will be great possibility to invest and provide loans for scale up SS technologies and services in the target areas.

During the interviews with residents, a question was about knowledge of the micro-credit loans for eco-toilets offered by XacBank (up to 7,000,000 MNT, at a monthly interest rate of 1.8-2.2 %) and willingness to pay if receiving such a loan. Another question was more precisely about willingness to pay by monthly installments during one year. In this context it has to be noted that both questions were not easy for respondents to answer since knowledge about micro-credits for eco-toilets is still not widespread in Mongolia. Only 30% of respondents answered that they knew about this loan opportunity.

Figure 5-6 shows the proposed financial mechanism and network which include the linkage/connection of micro-finance organizations with other major and active stakeholders towards scaling up sustainable sanitation technologies and services.

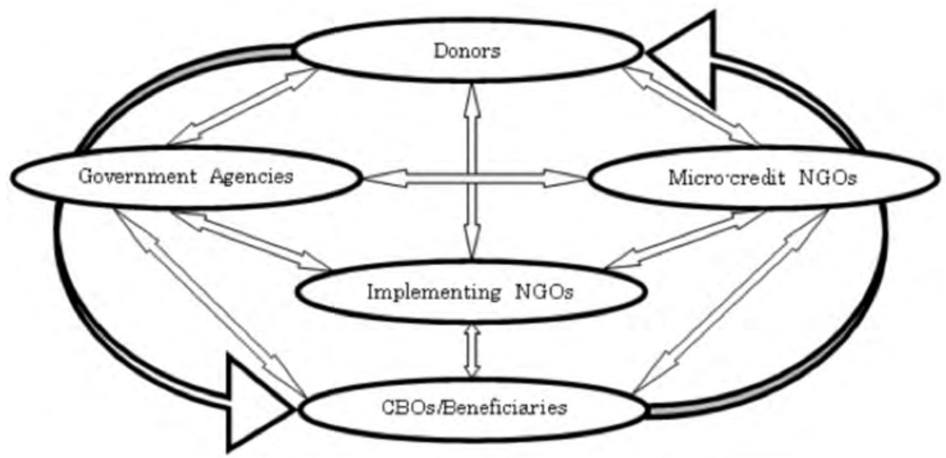


FIGURE 5-6 PROPOSED NETWORKING AND COORDINATION FOR FUND RAISING (ADAPTED FROM UDDIN, 2011)

If the providers/donors make effective networks with the micro-credit organizations, it might be one of the triggers to replicate SS technologies and services in the study area and beyond. It also might reduce the hazards and vulnerability of people from the possible risks of existing unhygienic and traditional water supply systems and sanitation technologies.

5.3.2 MAKING SS SELF-FINANCING FOR INFRASTRUCTURES AND SERVICES

There are possible business opportunities for organic fertilizer production in Mongolia. However, to establish the actual benefits and to quantify them in monetary terms from the companies involved remains a challenge. The results from the stakeholder interviews also showed that government and other stakeholders had shown keen interest in improving the situation of the Ger areas in terms of WASH, but very limited interest in the SS concept. On the other hand, several private companies showed business interest in managing the emptying services, installing eco-toilets and treatment of human feces through composting. These types of business possibilities should enhance the process for self-financing mechanisms in the study area and in other parts of the country.

Another opportunity was found during the key informant interview to explore the financial sources among the national and international companies and banks to develop the biogas system by using fecal sludge and other organic wastes in Mongolia to generate electricity from it. It also revealed that demand for organic fertilizer is high in Mongolia. Fecal compost and other organic fertilizer production for animal fodder would be a solution.

It will need a lot more initiative from the private sector to produce and marketing sustainable sanitation products. Right now ACF is interveting several programs and research on sustainable sanitation at small-scale to develop the advocacy tools for convincing more people both from government and non-government sectors.

5.3.3 TOWARDS CORPORATE WASH RESPONSIBILITY

The idea of corporate social responsibility (CSR) is not new and many theories, definitions and characteristics of CSR are well documented in a range of business and management literature [245, 246, 247, 248]. In addition, the concept of 'corporate environmental responsibility' (CER) has evolved from CSR in recent decades for improving the environmental impact of companies and other stakeholders [249, 250]. However, only very recently has it been addressed as a potential driver to solve global sanitary problems [251] and create finances for improving global WASH conditions significantly. The results from the key informant interviews and stakeholder interviews showed that CSR is absent from the field of WASH in Mongolia. A department of corporate environmental responsibility at the Trade and Development Bank has just started recently to deal with the mining industry and making loans to companies dependent on an environmental assessment. Following the same logic, 'corporate WASH responsibility' can be considered as one of the important components of CSR in banking and non-banking sectors to raise awareness among institutions and communities for improving both the local and the global WASH situation sustainably. Figure 5-7 shows the proposed linkage among three components of corporate responsibility. This linkage might enhance the WASH sector particularly deploying SS technologies and promoting services to improve and create funding for the continuing the programs in the intervention areas.

5.3.4 TOWARDS GOVERNMENT SUBSIDIES

Qualitative interviews among the stakeholders revealed that there is in principle a budget allocation by companies (e.g. mining companies) for local residents in Mongolia which could be used for wider sanitary improvement and to replicate SS technologies and services. Investment in the water and sanitation sectors would bring significant economic benefits. A one USD investment

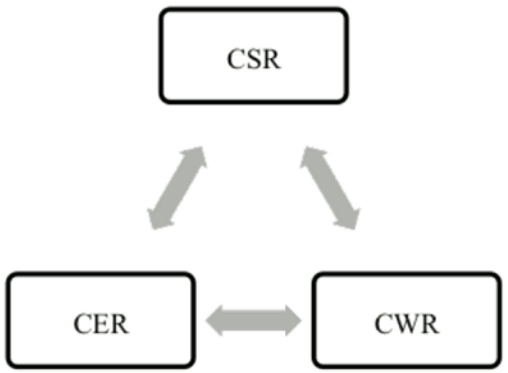


FIGURE 5-7 PROPOSED INTER-CONNECTION OF CSR, CER AND CWR.
(CSR-CORPORATE SOCIAL RESPONSIBILITY, CER- CORPORATE ENVIRONMENTAL RESPONSIBILITY,
CWR- CORPORATE WASH RESPONSIBILITY)

in both water supply and sanitation improvement would give an economic return between 3 USD and 34 USD based on the areas (WHO, 2004) [252]. The large public benefits involved in improving sanitation could encourage the Mongolian government, as any other, to perceive sanitation rather as a public responsibility, instead of a private good and the responsibility of households. Improving sanitation thus reduces public and private health-care costs and increase the population's productive days effectively. In Mongolia, the coverage of improved sanitation is 26.6% and of improved water supply is 39.2%. Progress during the last two decades has been very slow, so the country may not be able to meet the MDG target for water and sanitation by 2015 [253]. Although progress of improved water supply is a bit faster than improved sanitation coverage, water quality is still not ensured. However, the results from stakeholder interviews revealed that the Mongolian government recently showed great interest in actively supporting the sanitation sector in Ger areas. The Ulaanbaatar city municipality is working with UNICEF and the Mongolian Red Cross on ways to identify sanitation gaps and improved sanitation (and latrines in particular) in Mongolia. This kind of outreach and public support is a good indicator. The government has shown in the past that it is very supportive of environmental programs especially in the Ger districts because it recognizes that they are a disaster in terms of infrastructure and public health. And if the problems of sanitation remain unaddressed then the consequences will get even worse. This could motivate the government to raise funds and provide subsidies for deploying SS technologies and services in the study area and other parts of the country.

Key informant interviews also revealed that the Mongolian government has expressed support so far. That has not turned into a subsidy or a tangible program yet, but there will be some sort of program or additional set-up of the government in partnership with some of the organisations to focus on on-site sanitation. So far the priority of the government has been the central sewage system and it is understandable, because it has been backed-up with years of waste. The waste water treatment plans are not in good condition, they have to be renovated if not replaced. And this will be a very capital intensive project and require a lot of resources.

Government has been spending on air pollution. The flagship project of "XacBank" in the Ecobanking department is the clean-stove project. The clean-air fund is funded by the government and has provided subsidies of up to 90% for the stoves. And now the UB-clean-air-project, which is part of the Worldbank, is also providing subsidies. Together they are really able to impact access to these products and impact pollution in the Ger districts. It may be an indicator that the government is willing to spend on these environmental issues if they have the means.

5.3.5 SOCIAL CAPITAL TOWARDS GENERATION OF FUNDS

In any society, successful cooperation for long term mutual benefit depends on the cultivation of social capital (bonding-bridging-linking such as neighborhood relationships) which has been described by many researchers. It has been applied in a range of fields such as health, disasters, sociology, and engineering [254, 255, 256]. However, there is very limited research can be found in the WASH sector particularly in exploring the scope of funding for sustainable sanitation. Figure 5-8 shows the major components.

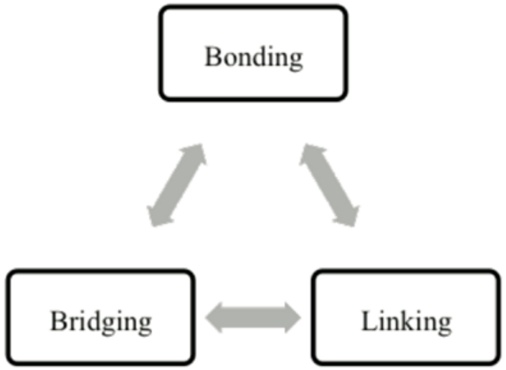


FIGURE 5-8 MAJOR COMPONENTS OF SOCIAL CAPITAL IN A SOCIETY.

Key informant interviews showed that social capital is lacking in the peri-urban settlements of the Ger areas due to the historical nomadic life of the people and rapid migration to the city areas. This may be one of the challenges to generating community funding mechanisms that should be applied to pay for SS technologies and services. This challenge can possibly be overcome by using community-based activities and programs executed by various governmental and non-governmental organizations. Very recent household survey on targeted greywater customers showed that 69% respondents know about their neighbors and 79% willing to help their neighbors if required in both monetary and non-monetary forms. This can be happened due to various initiatives and programs in WASH and health sectors by a range of non-governmental organizations including ACF Mongolia. Sixty seven percent of the respondents were willing to invest for the greywater treatment and the range of monthly payment which for two years was 10,000-115,000 MNT/5.45-62.65 USD. To save money 69% of the respondents were ready to share the installation and maintenance costs with their neighbors. The remaining respondents explained some factors for not sharing the system with neighbors, the factors include lack of good relationship, do not want to depend on neighbors, to get full ownership, and diseases of neighbors. This may be also applicable for other SS technologies and services in the study areas and beyond.

Involvement of informal institutions such as co-operatives, community based organizations, other social associations can be another direction for networking within the social capital boundary. They may play a leading role towards innovations and fund raising for solving any social issues including sanitary problems and natural resources management. Key players under the informal institutions include natural leaders, religious leaders, traditional community leaders, school teachers [257]. Social capital may increase the socio-cultural resiliency in the society among the people to develop the sustainable sanitation system, to keep the system well and monitor it properly towards sustainability of the SS technologies and services.

5.4 SUB-SUMMARY

The results from the customer survey shown that majority of the respondents (85%) dispose greywater to either pit latrines or soak pit and rest of the respondents dispose to the ground both inside and outside the household compounds.

The perceptions on greywater treatment and reuse options, except some maintenance and technological issues, were well understood by the 100 percent users of greywater. Based on the physical characteristics of the treated greywater, both GH-GWTU and IB-GWTU are accepted by the users due to their technical simplicity, availability of agro-lands in their household compounds, greywater management system, no bad smell and the good color of treated greywater. However, all the users generally accepted the treated greywater from both units, which indicates that improved models could be scaled up for meeting a part of the water demand in the Ger areas.

The economic issue is much concerned by government for greywater treatment and reuse options. As long as the price of new water is so cheap reusing greywater will not make economic sense for them in terms of reuse practices.

The survey results of the present study indicated that technologies and the services of SSS in the study area are socially accepted by all users of SSS toilets due to some factors. However, 80% of the respondents were not interested to consume the products produced by fecal matter.

The study also has explored funding sources at both community and institutional levels to scale up the system and its technologies in the study area and other parts of the country. Although there are potential benefits found from eco-toilets, the affordability to buy and willingness to pay is much lower than for installing a pit-latrine. There are micro-credit loans available for installing eco-toilets, but communities have negligible awareness and understanding of them.

6 - A SWOT ANALYSIS ON INTEGRATING SAFE WATER SUPPLY AND SUSTAINABLE SANITATION SYSTEM

6.1 STRENGTHS

Several organizations, such as ACF, UNICEF, World Bank, Xac Bank, and World Vision, work directly and indirectly with the WASH sector of Mongolia [39]. These organizations work at different levels, such as communities and schools, in the rural, peri-urban, and urban areas of Ulaanbaatar. Although insufficient in the Ger area context, the WASH interventions of these organizations can encourage future collaborations and plans for SWS–SSS integration. The presence of NGOs, including their local partners, as well as their strong interests toward WASH may result in the future acceptance and up-scaling of SWS and SSS technological interventions that can improve the overall health and environmental conditions in Mongolia. The strengths before the integration, such as the community interest toward SWS and SSS technological interventions, must be considered in the future designing and planning of various programs for encouraging active community participation. More than 500 water kiosks have been established in Mongolia where Ger residents collect their water for their drinking and other purposes [39]. However, the FGD data show that the quality of water from these kiosks, particularly the water storage, collection, transportation, and purification, is neither guaranteed nor monitored. Most Ger residents use second-hand and hazardous materials, such as plastic containers, to collect and transport water from the kiosks and to store them in their households. The traditional sanitation facilities, such as pit latrines and soak pits, may increase the vulnerability of the Ger area residents to WASH-borne diseases.

The scenario after SSS–SWS integration shows several strengths (Figure 6-1). For instance, the strong institutional network and effective coordination system for WASH intervention can enhance the capacity of organizations and communities for improving their awareness and participation in WASH-related initiatives by establishing a proper flow of WASH-related information. Moreover, the availability of training and education initiatives may increase the number of skilled workers in the Mongolian WASH sector. The establishment of a WASH information center can strengthen WASH-related research and development activities. Uddin et al. (2012) [69] reported that CBOs could motivate and educate people toward accepting and up-scaling sustainable sanitation technologies [69]. They likewise identified the "Tolgit" CBO as a key player in the sanitation of the Ger areas in Ulaanbaatar. The establishment of additional CBOs can help plan, design, and implement overall WASH-related activities in communities through the "bottom up" approach.

6.2 WEAKNESSES

Several weaknesses, such as the weak institutional network, the absence of coordination, and the lack of WASH-related policies, have been identified in Mongolia. No WASH-related policies have been implemented in Mongolia despite the immense potential of the country to incorporate or develop SWS —or SSS— related policies. Low income has likewise been identified as a weakness in the traditional sanitation system. Therefore, the weakness of the entire system negatively affects the entire society including study area. The lack of awareness on the cross-sectoral importance of WASH and on political will has been identified as a major cause of the weaknesses in the existing system (Figure 6-2).

Mongolia lacks a department or a ministry that can organize or formulate WASH-related activities and policies. The Ministry of Nature, Environment, and Green Development is responsible for increasing the water resources in Mongolia. Some WASH-related construction projects in the country are being handled by the Ministry of Construction and Urban Development. However, government departments and stakeholders in Mongolia do not coordinate with one another for the proper planning of policies and activities, which has been a long-standing issue in other low-income countries [258]. The WASH sector of Mongolia likewise lacks qualified and skilled workers, which has been identified as a major weakness. The weaknesses in the after SSS–SWS integration scenario include interest toward external funding, low income, and lack of infrastructures. Community funds must be collected considering the expensiveness of monitoring and maintaining SSS. The lack of subsidies and external funds may hinder the proper and effective maintenance of the system, which may be overcome by the proper planning and active involvement of government agencies and other stakeholders in WASH-related initiatives.

6.3 OPPORTUNITIES

No opportunities are found under the current and traditional sanitation systems. However, several opportunities may be created, such as WASH-related jobs, interventions, education, awareness, and material development, before the SSS–SWS integration.

The opportunities in the after SSS–SWS integration scenario include the establishment of the WASH Resource Center, which will be used as a source of information for various WASH actors inside and outside of Mongolia. A range of employment opportunities and business options can be created from the implementation, operation, and maintenance of SSS components, such as the development of multi-service water kiosks and the production of bio-energy and compost from human feces, greywater treatment and reuse. The composting of human feces may recover valuable nutrients for plants and humans, which will create business and marketing opportunities. Household greywater treatment and reuse can be considered as another business option for solving the water shortage problem in the Ger areas of Ulaanbaatar. Effective sanitation marketing may be implemented in the WASH sector of Mongolia, such as the development of an emptying service system for urine-diverting toilets, the composting and application of human feces from these toilets, the application of sanitized urine in agricultural lands, the recovery of nutrients through other processes, and the production of bio-energy. The compost that is produced from human feces and treated greywater can be used in home gardening, which is a common interest among the residents of Ger areas. The compost can likewise be applied for greening cities and other horticultural lands.

FIGURE 6-1 COMBINED WASH-BORNE STRENGTH AFTER SSS-SWS INTEGRATION.

FIGURE 6-2 ROOT AND UNDERLYING CAUSES OF WASH-BORNE WEAKNESSES.

6.4 THREATS AND WASH-BORNE HAZARDS

The existing and conventional system with unimproved technologies such as pit latrines in the Ger areas of Ulaanbaatar have been identified as threats to the SSS–SWS integration. The lack of a drainage system in the Ger areas prompts the residents to use pit latrines or soak pits to drain greywater, which causes flooding in the roads as well as in and out of households. The threats before SSS–SWS integration include the extreme cold climate, the existence of non-environmental-friendly technologies (i.e., pit latrines), and the lack of political willingness, whereas the threats after SSS–SWS integration include the extreme cold climate, the urbanization and migration, and the existing pit latrines. The improvement and proper integration of SWS into SSS may solve the threat of the extreme cold weather. Following are the WASH-borne hazard threats which could be the combined threats due to the current existing system:

6.4.1 WATER-BORNE HAZARD THREATS

Results from the KAP survey indicate that water kiosks (Figure 6-3) account for the main source of water supply for both drinking and non-drinking purposes in the peri-urban Ger areas for the majority of respondents. Some water kiosks are connected to the central water supply network, while others are fed by water tank trucks managed by the Ulaanbaatar Water Supply and Sewage Authority (USUG). Other sources of water, such as unprotected private boreholes and springs, are also used by some of the respondents: 15.4% of respondents reported using private boreholes, while 2.5% of interviewees reported using spring water. The use of plastic containers is almost exclusively used for the transportation (94.3%) and storage (92.4%) of water.

FIGURE 6-3 WATER KIOSK, CONTAINER, AND TROLLEY USED FOR WATER COLLECTION AND TRANSPORTATION IN THE GER AREAS. (FIELD SURVEY, UDDIN, JULY, 2012 AND NOVEMBER, 2013).

Presently in Mongolia, coordination between stakeholders from the government and civil society is weak, especially with regards to solving environmental sanitation challenges in peri-urban settings. The present approach is centralized and functions at a very slow pace. The government aims to provide a centralized system for 40% of the population by 2015.

There currently is no policy to encourage a decentralized system. In the Ger areas, water kiosks are the only way to access water for drinking, cooking, and cleaning purposes. The water kiosks can either be fed from a central water connection or by water tanks. Water in the Ger areas is mainly provided by approximately 550 public water kiosks, where the average water consumption is 10 liter/person/day [39].

The results from the water quality analysis show higher contamination in the summer than in the winter. However, the contamination in both seasons does not meet the Mongolian drinking water quality standard (MNS ISO 4697-1998: drinking water should not contain *E. coli* bacteria levels that exceed WHO 2008 guidelines for drinking water). The water quality analysis (Table 6-2) conducted in the winter illustrates that 36% of drinking water samples taken at the household level was contaminated by *E. coli* with low-to-high levels of health risks. The average number of *E. coli* in the contaminated drinking water samples was 12.5ml per 100ml, with a range of 1ml–52ml. There were two water kiosks out of 40 total sampled that were found to be contaminated by *E. coli* during the winter. To show the contamination of households around the contaminated water kiosk, 6 samples were collected and tested, showing that the drinking water of all households was contaminated at levels as high as 31 *E. coli* per 100ml.

TABLE 6-2 CONTAMINATED DRINKING WATER BY *E. COLI* AT THE HOUSEHOLD LEVEL.

SEASON OF SAMPLING	PERIOD OF SAMPLING	CONTAMINATED HOUSEHOLDS (n=210) 10% PRECISION	% HOUSEHOLDS CONTAMINATED	AVERAGE NUMBER OF *E. coli*	RANGE OF *E. coli*
Winter	Dec 2012- Jan 2013	76	36	12.5	1-52
Summer	May-June 2013	117	55.71	50	1-404

On the other hand, households shows that over half of the samples were contaminated by *E. coli* with an average of 50 *E. coli*/100ml of drinking water. There were five water kiosks found to be contaminated among the 40 samples, two of which were highly contaminated by *E. coli*: 120 and 189 *E. coli*/100ml water. The sources of the above contamination at the household level may be due to the collection and transportation processes from the water kiosks using low quality containers. Water contamination during the summer is much higher than the winter, including at water kiosks. Water kiosk contamination might not only depend on the types of water supply (either piped or tank water supply), but also the maintenance of the pipes and tanks.

KAP survey results shows that 57% of the respondents among the surveyed households do not boil water before drinking, which may very well increase their risk of water-borne disease. Moreover, the majority of respondents use containers that are secondhand, unhygienic, and old for water collection and storage. 79.5% of respondents use second hand containers to transport water, while 84.3% of respondent use secondhand containers to store water. These unsafe water supply, transportation, and storage practices increase the hazards of the Ger residents to waterborne disease.

Although the UN (2013) suggests that individuals have access to 20-50 liters of water daily for drinking, cooking, and cleaning purposes [3], the average consumption of Ger residents is very low at 10 liter/person/day [39]. KAP survey results show that the average consumption is 8 liter/person/day, which drops to 4 liter/person/day during the winter. There are several factors accounting for low consumption of water in the Ger areas, including distance of water kiosks from households, short period of daily distribution, consumption differences between the winter and summer months, low frequency of bathing outside the compound (public bath), irregular cloth washing, and reuse of water without treatment.

The results from the KAP survey illustrate that 51.4% of households have soak-pits in their compound to discharge greywater, while 40% of households pour greywater into their pit latrines. The rest of the households discharge greywater onto the roads, in yards, or in other places. Ger residents frequently discharge their greywater into pit latrines, soak-pits, yards, and on open streets, which causes immediate environmental pollution and health hazards due to high concentration of chemical agents in the greywater. In the warmer months, the same practices lead to even greater environmental degradation, as well as favorable conditions for vectors to breed.

6.4.2 SANITATION-BORNE HAZARD THREATS

A range of sanitation technologies that are not recognized as improved sanitation technologies, such as unimproved pit latrines (Figure 6-4), soak pits for greywater discharge, and unplanned sites for solid waste disposal have been identified in the Ger areas.

FIGURE 6-4 UNIMPROVED AND UNHYGIENIC PIT LATRINES IN THE GER AREAS.
(FIELD SURVEY, UDDIN, APRIL 2012).

Over 80,000 pit latrines were estimated to solve the majority of sanitation problems, yet most of the technologies are unimproved and unhygienic due to the low maintenance, technological drawbacks, and poor quality. As a result, users are often exposed to contact with pathogens that result from the contamination of groundwater sources. The KAP survey illustrates that 96.7% of respondents use domestic and shared pit latrines, which are categorized as "unimproved sanitation facilities". The rest of the respondents use public toilets, a neighbor's latrine, "ecosan" toilets, and/or open defecation. Common problems encountered with the current toilets are pit filling (43.1%), odor (41.1%), cold conditions (26.3%), flies (21.5%), and safety of use (17.2%) (15.3% of respondents said there were no problems).

During the rainy season, the lack of a proper drainage system results in frequent flooding. The problem is exacerbated by the fact that Ger residents often dispose of garbage in flat areas, which are often subject to the flooding. Exposure to waste-borne contaminants further exposes residents to pathogens. Moreover, the high concentration of household wastewater draining to yards, roads, and areas surrounding housing compounds also create health and environmental hazards for residents. A failure on the part of the government to invest in the infrastructural development of Ger areas makes these challenges even harder to combat.

Key informant interviews with doctors revealed that the hazardous WASH situation, particularly due to biological and chemical contaminants in surrounding peri-urban Ger and mountainous areas, may have potential to harm the population living in the central urban areas due to rainfall, flooding and runoff during the summer months.

6.4.3 HYGIENE-BORNE HAZARD THREATS

KAP survey results show that 52.4% of respondents wash their hands after engaging in unsanitary activities, 36.4% after changing diapers, 27.7% before cooking, 23.3% before eating, and 20.9% after defecating. Among the respondents who wash their hands, 33.8% do not use soap, whereas 56.7% use soap during hand washing. Engaging in unhygienic practices significantly increases vulnerability to human health hazards. When respondents' were asked if water could transmit diseases, 52.4% replied yes, 15.7% replied no, and 31.9% replied that they did not know.

There were several challenges that were revealed from the study conducted in schools in the peri-urban settlements of Ulaanbaatar, including the lack of appropriate WASH facilities, unavailability of soap, and inadequate hygiene promotion among students. The survey results among the school students show that 59% of students do not wash their hands, 34% wash their hands with water only, and 5% wash with water and soap, bringing their own soap from their homes.

Hospitals are particularly sensitive areas where proper hygiene practice, safe water, and proper sanitation facilities should be considered to further reduce risk of infection. The results of the hospital study in the Ger areas revealed that no soap is provided for washing hands inside the hospital, including in bathrooms. A key informant interview with a doctor revealed that most of the patients affected by diarrhea and dysentery are children under five years of age, the majority of which visit the hospital frequently (once or twice in a month) for treatment. Public health data, particularly in Ger areas, is not available. National health statistics gathered at the district and national levels do not separate Ger areas, making comparisons between Ger areas and other urban areas difficult [259]. Table 6-1 shows the overall threats and hazards and possible solutions.

TABLE 6-1 EXISTING THREATS AND THEIR POSSIBLE SOLUTIONS.

FACTORS	EXISTING THREATS	POSSIBLE SOLUTIONS
Technological	The existing unhygienic pit latrines and unsafe water supply systems, including water transportation, collection, and storage [38, 37, 260], may threaten the health of Ger area residents. The lack of a drainage system in these areas prompts the residents to drain their greywater through pit latrines, soak pits, and yards, which may cause health hazards or environmental problems.	Technology innovation and sustainable sanitation technologies, such as urine-diverting toilets and household greywater treatment systems, may reduce these threats [94]. The proper monitoring of water transportation, collection, and storage systems may ensure SWS. The extreme cold weather can be handled by the improved sustainable sanitation technologies [261].
Political	Mongolia remains "off track" in satisfying the sanitation MDGs [35]. The government lacks the willingness and interest toward implementing policies that can improve the sanitary conditions of the country, including those of the Ger areas.	The proper SWS-SSS integration may motivate political leaders to formulate WASH-related policies.
Financial	The lack of financial support from the government to endorse technological innovations and improve the overall sanitary condition of the Ger areas.	The success and benefits of the SWS-SSS integration may encourage the government to lend financial support as well as to involve themselves in future sustainable sanitation-related activities.
Social	Despite the high demand, sustainable sanitation technologies have a low social acceptability because of the lifestyle, attitude, and nomadic mentality of the Ger area residents. Moreover, the unplanned rural migration into the peri-urban Ger areas of Ulaanbaatar threatens the effective SWS-SSS integration.	SWS/SSS awareness and education may change the behavior and attitude of the Ger area residents, which may increase their social acceptance of sustainable sanitation technologies [69].
Health	A higher prevalence rate of waterborne diseases is observed among the Ger area residents. The children are especially prone to these diseases. Approximately 10,000 cases of diarrhea are recorded in Mongolia every year, which is the most prevalent disease followed by dysentery. The prevalence rate of hepatitis A in Ulaanbaatar is seven times greater than the international average [37]. The health hazards in Ulaanbatar may be attributed to the lack of SWS-SSS integration.	The holistic/comprehensive sustainable sanitation approach can dramatically reduce the waterborne diseases in the study area and beyond [69]. The improved waste management, water supply and sanitation, awareness (through education and literacy), and proper drainage system can be included in the integration process to overcome these threats.

6.5 TOWARDS SUSTAINABLE SANITATION SYSTEM

FIGURE 6-5 SUSTAINABLE SANITATION SYSTEM.

Figure 6-5 shows the proposed mechanism of the sustainable sanitation system for the vulnerable communities in peri-urban Ger areas of Ulaanbaatar, In this study, household greywater and human feces treatment and reuse are considered as major parts of the SSS where high concentration (e.g., COD) of greywater can be treated and reused to prevent health and environmental hazards and solve the water scarcity problem in the area to some extent. Human feces can be treated through composting within the closed-loop sanitation system to prove the feasibility of the system, prevent the proliferation of WASH-borne diseases, and recover resources. Water supply chain in the area can be protected by proper integration with SSS to prevent potential contaminations that are caused by unplanned greywater discharge and by unimproved sanitation technologies.

As the overall removal rate of different parameters of both GH-GWTU and IB-GWTU was satisfactory and a removal rate of over 90% was achieved for all parameters, these technologies have high potentiality to reduce the contaminants significantly. Results from composting human feces in both SC-WCU and SC-GHCU proved to be technically feasible which can also have potentiality to reduce WASH-borne risks and hazards in the study area and other parts of the country. In the SC-GHCU, over 70ºC of pile temperature was achieved and the average ambient temperature in the facility was over 20ºC maintained. More than 50ºC for 9 days which meet the international standards in terms of temperature and pathogen die-off. Biological test results indicated that there was not a single Salmonella and *E.coli* found in the compost. In addition, there was no indicator bacteria found in the products (e.g. Spinach) produced by fecal compost. Conversely, the compost produced demonstrated qualities in term of productivity.

6.6 IMPLICATION OF FINDINGS- WAY TO REDUCE WASH AND GREYWATER-BORNE HAZARDS

There are various interventions and initiatives around the world that are considered effective ways to reduce WASH-related risks and hazards. Effective preventative measures are considered to be at the heart of proper risk management, with a focus on providing safe drinking water [262]. A systematic review [263] shows that all of the intervention studies were found to significantly reduce the risk of diarrheal illness with a similar degree of impact. Less *E. coli* contamination of stored water and a lower incidence of diarrhea were found in the households benefitting from 'point-of-use' water treatment versus households serving as controls [264]. Some studies show that providing both toilets and safe water supply systems can reduce the incidence of cholera by as much as 76% [265]. Aiello et al. (2008) shown that hand-hygiene practices alone can reduce the incidence of gastrointestinal disease by 31%, thereby illustrating the effectiveness of hand washing in preventing gastrointestinal illness [64]. Likewise, Cairncross et al. (2010) show that hand washing with soap can reduce the risk of diarrhea up to 48% [266]. Adequate practices of environmental sanitation can reduce incidences of pathogen-positive diarrhea among children by 40% [267]. In addition, raising public awareness and conducting systematic monitoring are often recommended as ways to reduce exposure [62]. Even when dealing with a good sanitation system, which isolates fecal matter from the human environment, other interventions must be simultaneously implemented to prevent other exposure pathways [268]. For example, combined use of chlorinated stored water, latrines and rainwater may significantly decrease diarrheal risk. Various alternative treatments and solutions are proposed to control the physical, chemical and microbial risks of reusing greywater as well as for non-potable use in both industrial and non-industrial sectors. All of the aforementioned findings are applicable to Mongolian Ger settlements and should be used by policymakers to inform WASH policies and reduce WASH-borne hazards.

Figure 6-6 shows the link between sources of WASH-borne hazards and possible interventions and solutions that could be implemented to reduce them. Strong WASH-related policy making and enforcement would greatly improve environmental health in Ger areas. A holistic/integrated approach to safe water supply and sustainable sanitation practices has the potential to prevent exposure to dangerous contaminants. Various media and communication tools and techniques can be used to increase communities' awareness of good hygiene and sanitation practices to reduce exposure to WASH-borne hazards in households, hospitals, and schools. These initiatives will activate the process towards ecological urban development, which, in turn, may reduce WASH-borne hazards in Ger areas. Environmental regulation alone cannot ensure the prevention of hazards nor reduce exposures [62]. However, a holistic approach to safe water supply and sustainable sanitation systems – coupled with the introduction of appropriate policies and regulations – may reduce WASH-borne hazards [68]. Scaling up of sustainable sanitation technologies may reduce WASH-borne diseases significantly [160, 69]. Proper sanitation and awareness campaigns are other essential components to encourage appropriate hygiene practices in the school, hospital, and household settings. Innovation in sustainable sanitation through resource/nutrient recovery from organic waste – including human waste – also contributes to preventing WASH-borne hazards. Finally, in order to be sustainable, sanitation systems have to be economically viable, socially acceptable, technically feasible, and eco-friendly.

The current study addresses multidimensional problems associated with WASH and exposure risks present in peri-urban areas of Ulaanbaatar, Mongolia. The study revealed that poor infrastructure in the peri-urban settlements is highly correlated with a low standard of living. The transmission of WASH-borne diseases is the gravest human health hazard the study area, which is likewise the case for many low- and middle-income countries in urban and peri-urban settings. Summer is a more hazardous season, as biological pathogens proliferate much faster in summer conditions, thus significantly increasing people's personal exposure levels.

To tackle these challenges and problems, a range of appropriate interventions are recommended to reduce the exposure of WASH-borne hazards in the study area and other parts of the world with a comparable context. The development and implementation of a water safety plan (WSP) and effective monitoring system for collection, transportation and storage at both the water kiosk and household levels are essential to protecting water from both biological and chemical contaminants. Unprotected private boreholes and springs should also be considered in the WSP. The users of water containers should be oriented through awareness-building and educational activities on washing and hygiene practices for water collection and transportation from water kiosks and storage at the household level. Effective coordination among stakeholders, including urban planners, may be useful to tackling WASH-borne hazards in an integrated manner. An appropriate water kiosk operational monitoring system should be developed to supply water to communities for a longer period of time and during both summer and winter months. Household greywater disposal should also be planned so as to protect both human and environmental health from chemical and biological contaminants. Due to the absence of a drainage system, appropriate decentralized solutions are encouraged to avoid high costs associated with conventional sewage system implementation. An appropriate solid waste management system based on the 3R system (i.e. reduce, reuse and recycle) would improve environmental health in the study area and beyond. Moreover, improving the WASH situation in peri-urban Ger and mountainous areas will ultimately protect communities in the urban center of Ulaanbaatar from runoff water containing both biological and chemical contaminants.

FIGURE 6-6 WASH-BORNE HAZARDS AND POSSIBLE SOLUTIONS TO REDUCE HAZARDS.

Various technological and non-technical solutions are proposed to reduce the greywater-borne vulnerability in the study area which can be replicable to other parts of the world. A holistic or integrated approach has been already proposed to reduce the water, sanitation and hygiene (WASH)-borne hazards and can be applied to reduce the greywater-borne vulnerability in the present study area. The study suggested both technological and policy-oriented initiatives to reduce the WASH-borne hazards. Given the lack of legal regulations and treatment infrastructure for greywater in Mongolia, both policy and technological introduction would be useful directions for the government to successfully address the greywater concerns in the study area and other parts of the country. Although economic cost recovery through greywater treatment and reuse is a salient and highly discussed topic at the governmental level, these discussions have not focused on the hazards and vulnerability to the environment and to human health resulting from greywater contamination. Moreover, the challenges faced by residents in collecting water and subsequent contamination of surface and groundwater sources are also omitted from the policy discussions. Advocacy tools and experimentation of various technological options and social dialogue can be constructive catalysts for the government to consider relevant regulations or policies for onsite, decentralized greywater treatment and reuse options in Ger areas.

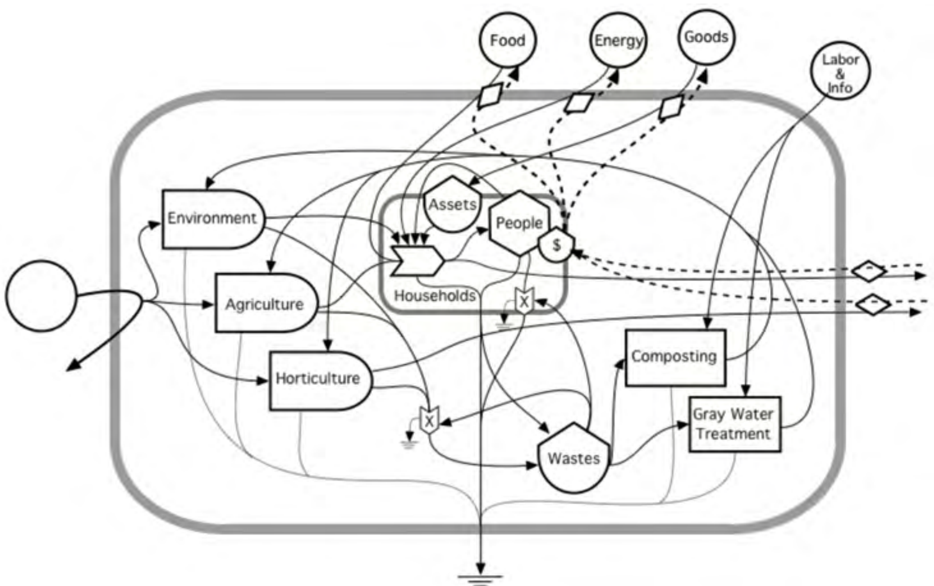


FIGURE 6-7 IMPROVED HEALTH AND ENVIRONMENTAL SYSTEM BASED ON HUMAN FECES COMPOSTING AND GREYWATER TREATMENT.

In this study, the feasibility and potentiality of composting and household greywater treatment technologies may lead the society towards greywater and compost oriented improved human and environmental health system (Figure 6-7) where several external sources of materials (e.g. sun, wind, food, energy, goods) are needed to enhance the treatment processes with the active influence of internal materials, actors and services (e.g. people, labor, asset, waste). The nutrients and treated greywater produced from this process can be internally used to the agriculture, horticulture and environmental remediation which ultimately lead towards an improved environment and human health systems which ultimately contribute to the sustainable sanitation system in the study area which can be replicable to other parts of the world.

6.7 SUB-SUMMARY

The scenario before SSS–SWS integration demonstrates few strengths, such as the interest of communities and NGOs toward SWS and SSS, which facilitates the acceptance and up-scaling of related technologies. The conceptual scenario after SSS–SWS integration, which has been constructed based on the previous literature and stakeholder interview data, demonstrates additional strengths, such as community acceptance, satisfaction with SSS, and development of SWS for a vulnerable population. The identified weaknesses are attributed to the lack of CBOs, community participation, policies in the WASH sector, and inter-sector coordination. The marketing of SSS, the involvement of banks and micro-credit systems, the reuse of treated greywater as a source of plant nutrient, and the strengthened inter-sector coordination have all been identified as opportunities from the integration. The threats before the SSS–SWS integration include the extreme cold, the use of pit latrines, and the lack of political will, whereas the threats after the SSS–SWS integration include the technological innovations that deal with the extreme cold, the demand for SSS technologies, and the increased interest of central and municipal governments.

The findings support the integration of SWS into SSS to decrease the prevalence of waterborne diseases that are caused and transmitted by fecal-contaminated water to improve the overall environmental condition in Ulaanbaatar. Such integration can likewise reduce water consumption, recover resources (i.e., plant nutrients), and improve soil conditioners to fulfill future nutrient demands. Moreover, the integration can reduce the weaknesses and threats of the existing system and convert them into sustainable strengths and opportunities.

7 - CONCLUSIONS, RECOMMENDATIONS AND NOVELTY STATEMENT

7.1 CONCLUSIONS

In this study, multiple sustainable sanitation technologies were designed, constructed, evaluated and monitored for the first time in vulnerable peri-urban Ger areas of Ulaanbaatar, Mongolia. Major general conclusions are presented below:

- Household based GH-GWTU and IB-GWTU were designed, constructed and tested in the study area for the first time and a satisfactory result was achieved in terms of significant reduction of chemical and biological contaminants from greywater. Results shown that a maximum removal rate of over 90% was achieved for all parameters. As for the IB-GWTU, the overall performance of the system provided very satisfying results than the GH-GWTU. The study proved that both technologies are feasible in the study area of Mongolia and can be replicable partly or fully either at household or community/cluster level in other parts of the world.
- WWdesigned, constructed and tested for the first time in peri-urban Ger areas in the study area. Results from composting human feces in SC-WCU shows that the temperatures above 55 and 65ºC were maintained for 2 weeks and more than a week respectively, which satisfies all the sanitation requirements including Germany standard. In the SC-GHCU, over 70ºC of pile temperature was achieved and the average ambient temperature in the facility was over 20ºC maintained. More than 50ºC for 9 days which meet the international standards in terms of temperature and pathogen die-off. Biological test results indicated that there was not a single Salmonella and *E.coli* found in the compost. The compost also proved to be safe in terms of heavy metal content. However, although both technologies are technically feasible, SC-GHCU might be more economically feasible than SC-WCU in terms of energy consumption which may need high costs.
- Results shown that the greywater and human feces treatment units are technically feasible towards meeting international standards/guidelines for greywater reuse and compost products, and socially acceptable by the most vulnerable communities and able to close the study area's sanitation loop in a manner that could be replicable in other parts of the world. These technologies are proved to be feasible in the cold climate regions and also in a condition where people produce less greywater with high concentration of both chemical and biological agents.
- The findings support the integration of SWS into SSS to decrease the prevalence of waterborne diseases that are caused and transmitted by fecal-contaminated water to improve the overall environmental condition in the study area and other parts of the world. Micro-finance, social capital, corporate WASH responsibility can be considered as potential sources of funding for replicating technologies and services in the study area and other parts of the low and middle-income regions.

7.2 RECOMMENDATIONS

Onsite greywater treatment systems are encouraged to treat greywater before re-use or discharge to the environment and to protect human and environmental health. Proper legislation on greywater treatment, production and discharge or reuse is needed to safeguard human health and the environment. Environmental education and awareness may help the population to be aware about the usage of chemical detergents and encourage more environment friendly and bio-degradable cleaning products. Such practices can substantially reduce both health and environmental risks. Further research on environmental and health consequences related to untreated greywater discharge is needed to assess the risks and hazards in this unique context. Monitoring of the treatment system throughout the year is suggested in order to examine the effect of temperature on the operation, maintenance and treatment process. The analysis of other chemicals including sodium, zinc, aluminum and heavy metals is also suggested to examine further risks that these may contribute for greywater production. Future studies could examine the effect of natural freezing conditions on removing physical and chemical contaminants but also to deactivate *E. coli* in the greywater. Such analysis would be particular relevant given the long winter season in Ulaanbaatar.

It is recommended to scale up the semi-centralized composting units among the cluster or community level to reduce the WASH-borne hazards and to recover resources and to protect human and environmental health. A detailed economic study for all those technologies and services including maintenance is essential to replicate in the low and middle income regions. An assessment of healthcare costs and other hidden/opportunity costs under the economic study would encourage advocating government agencies to provide subsidies for scaling up SS technologies and services countrywide. Even though Mongolian health insurance covers basic treatment, water-borne diseases lead to financial costs for households in addition to personal constraints and discomfort. Building social capital among the Ger residents may also have added value to generate community funds for monitoring and maintaining the technologies and services at scale. A re-invented idea of 'Corporate WASH Responsibility' is highly recommended to explore in future studies towards sustainable sanitation, proper healthcare system and water resources management. Enforcement of environmental laws and other related laws may also help reduce the costs associated with unsanitary/insufficient WASH facilities in the study area and other parts of the low and middle-income regions. An integration of SWS and SSS is highly recommended to reduce the vulnerability of the communities to WASH and greywater-borne diseases. The financial sources and cost recovery of the SWS–SSS integration must be explored further to lift the burden of the poor residing in the study area and in other parts of the world.

A detailed study on the 'peri-urban-to-urban' context is proposed to assess the WASH-borne pollution load/mobilization from peri-urban to central urban areas. More specifically, the study can shed light on waterborne pollutants' modes of action, as well as help to characterize the vulnerability of populations in both peri-urban and urban areas.

7.3 NOVELTY STATEMENT

I. The sustainable sanitation technologies that has been tested comprehensively for the first time in the coldest capital of the world, Ulaanbaatar, Mongolia on household greywater and human feces treatment which are feasible in long winter/cold weather and water stressed regions and can be replicable partly or fully in other parts of the world to reduce both chemical and biological contaminants for better health, environment, and resource/nutrient recovery.

II. The study discovered that the sustainable sanitation technologies are socio-culturally acceptable by the most vulnerable and nomadic-cultured communities in the study area due to the monetary and non-monetary benefits and business opportunities which has potential to increase the living standards of the low income people. These technologies can be replicable in other parts of the world with the support of alternative and re-invented financial sources which have been identified and clarified for potential fund generation from local to global level.

III. The study confirmed that an integration of Safe Water Supply and Sustainable Sanitation System has high potential to reduce water, sanitation and hygiene (WASH) and greywater-borne hazards in the study area. This integration can be applied to other parts of the world to significantly reduce the contaminants and threats associated with WASH and greywater which can ultimately support in reducing the WASH and greywater-borne mortalities at global level.

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ANNEX: SAMPLE QUESTIONNAIRE 1

Name:	Interviewer:
Sex:	Date:
Age:	Survey Area:

1. Toilet Situation

#101	What kind of toilet you use:	[1] Eco-toilet [2] Pit latrine [3] Others

2. Old Situation

#201	What toilet did you use before you had the Eco-Toilet?	[1] Pit latrine (unsealed) [2] Pit latrine (sealed) [3] VIP [4] No toilet [99] Other
#202	How much money did it cost to build your old latrine?	Approximately ...... MNT
#203	What kind of maintenance work did you need to do?	
#204	What do you think about maintenance?	[1] Expensive [2] Moderate [3] Cheap Please specify yearly amount ...... MNT

3. Comparison of Old and New Toilet/Benefits

#301	In general, do you prefer your old toilet or the Eco-Toilet?	[1] Old toilet [2] Eco-toilet [3] Don't know
#302	What are the main advantages of your Eco-Toilet?	
#303	What are the main disadvantages of your Eco-Toilet?	
#304	Why did you start using the Eco-Toilet? Choose all applicable	[1] Comfort (Comfortable use) [2] Cheap/For free [3] Quality (Long lasting) [4] No environmental pollution [5] More hygienic (Cleaner, less flies) [6] Less odour [7] Faeces will be collected [99] Other, Wspecify ......
#304	Compared with the old situation, how is the Eco-Toilet with reagrd to:	
	Maintenance	[1] Easier [2] More difficult [3] No difference
	Comfort	[1] Better [2] Worse [3] No difference
	Safety	[1] Better [2] Worse [3] No difference
	Costs	[1] Cheaper [2] More expensive [3] No difference
	Hygiene	[1] Better [2] Worse [3] No difference
	Quality (Lifetime)	[1] Better [2] Worse [3] No difference
	Flies	[1] Less [2] More [3] No difference
	Odour	[1] Less [2] More [3] No difference
#305	Do you think the environment will be better by using the Eco-Toilet?	[1] Yes, please specify ...... [2] No, please specify ...... [3] Don't know
#306	What has changed in your daily life since using eco-toilet? (e.g. Less sick, more leisure time, more convenience, less work digging hole, more comfort, environment cleaner?)	
#307	Do you think the environmental conditions in your area have changed?	[1] Improved [2] Slightly improved [3] No change [4] Slightly deteriotated [5] Deteriotated

4. Health

# 401	Has one of the following diseases affected any member of your family (**over 12 years old**) in the last 12 month? *Indicate number of people*.	
	Diarrhea	[1] Yes [2] No [Number]

	Dysentery	[1] Yes	[2] No	[Number]
	Hand-foot-mouth disease	[1] Yes	[2] No	[Number]
	Hepatitis A	[1] Yes	[2] No	[Number]
	Helminthes (Worms)	[1] Yes	[2] No	[Number]
# 402	Has one of the following diseases affected any member of your family (**under 12 years old**) in the last 12 month? *Indicate number of people*.			
	Diarrhea	[1] Yes	[2] No	[Number]
	Dysentery	[1] Yes	[2] No	[Number]
	Hand-foot-mouth disease	[1] Yes	[2] No	[Number]
	Hepatitis A	[1] Yes	[2] No	[Number]
	Helminthes (Worms)	[1] Yes	[2] No	[Number]
#403	How far is the next health centre?			
#404	How does a diarrheal disease affect your daily activities?	[1] Able to conduct daily activities with only minor inconveniences [2] Able to conduct daily activities with major inconveniences [3] Unable to conduct daily activities [4] Never been affected by diarrhoeal		
#409	How many days are you usually constrained in daily activities, if affected by Hepatitis A?	Approximately ...... days		
#410	Where are you seeking medical treatment if you are affeted by hepatitis A?	[1] Health centre [2] Hospital [3] Self treatment [4] No treatment [5] Other, please state		
#411	How much money you spend on drugs if affected by Hepatitis A?	Approximately ...... MNT		
#412	Compared to the past (when you did not have an Eco-Toilet): Has the health situation (including affection by waterborne-diseases) in your household changed?	[1] Improved [2] Slightly improved [3] No change [4] Slightly deteriotated [5] Deteriotated [6] Don't know Please specify		

5. Financial Aspects

#501	Did you pay for your Eco-Toilet?	[1] Yes, please specify amount ...... MNT [2] No
#502	Did you contribute to the construction of the Eco-Toilet?	[1] Yes, building of the superstructure [2] Yes, other please specify ...... [3] No
#502A	How much money and labour did you spend for building the superstructure?	[1] Amount spend ...... MNT [2] Hours worked ......
#503	Did you have to do any maintenance since using the Eco-Toilet?	[1] Yes, please specify what ...... [2] No
#504	Do you think maintenance of the toilet is expensive?	[1] Expensive [2] Moderate expensive [3] Cheap [4] Very cheap
#505	What do you use to cover faeces?	[1] Straw [2] Sawdust [3] Ash [4] Other Amount per month spend ...... MNT
#506	Did you know that Xac-Bank is offering microcredit loans, for buying eco-toilets? (Up to 7.000.000 MNT, 2% interest rate per month)	[1] Yes [2] No
#507	Would you be interested in such a loan, if you were to buy a Eco-Toilet?	[1] Yes [2] No
#508	Which of the following latrine packages would be most interesting for you?	[1] NGO provides base and I built superstructure by myself [2] NGO provides base and I pay some-one to build superstructure for me [3] Build whole Eco-Toilet myself [4] Pay someone to build it completely
#509	Would you pay ...... MNT to buy the Eco-Toilet?	[1] Less than 200.000 [2] 200.000 [3] 300.000 [4] 400.000 [5] 500.000 [6] 600.000 [7] 700.000 [8] 800.000 [9] More than 900.000 MNT

#509 If you were able to a receive a loan (up to 7.000.000 MNT, 2% interest rate per month), would you pay ...... MNT to buy the Eco-Toilet?	[1] Less than 200.000 [2] 200.000 [3] 300.000 [4] 400.000 [5] 500.000 [6] 600.000 [7] 700.000 [8] 800.000 [9] More than 900.000 MNT
#510 Do you think Eco-Toilets should be subsidised?	[1] Fully [2] Partly [3] No subsidies [4] Don't know If yes, please state why? ......
#511 What do you think are the main barriers for buying a Eco-Toilet?	[1] Affordability [2] No interest in another toilet [3] Not comfortable [4] No good design [99] Other, please specify ......

6. Socio-Economic Questions

#601 How many members has your household (inlcuding you)?	[1] Less than 2 [2] 2 [3] 3 [4] 4 [5] 5 [6] 6 [7] 7 [8] 8 [9] More than 8
#602 How many household members are under the age of 18?	[1] 1 [2] 2 [3] 3 [4] 4 [5] More than 5
#603 Do you have an occupation?	[1] Yes, please specify ...... [2] No

ANNEX: SAMPLE QUESTIONNAIRE 2

ECO-TOILETS: OPERATION & MAINTENANCE

Name:	Questionnaire Nº:
Gender: [1] Male [2] Female	Investigator: Survey Area:
Occupation:	Date:
Phone:	
Respondent agreed to be interviewed: [1] Yes [2] No	

1. Toilet Situation

#101 What type of toilet are you using?	[1] Zip Zap Eco toilet [2] Raised Eco toilet [3] Double Vault solar [4] UDDT
#102 Why are you using this type of toilet? *(Choose all applicable)*	[1] No bad smell and flies [2] No water and environmental pollution [3] Users friendly [4] Specify others ......
#103 When did you start using this toilet?	[1] 1 — 5 Months [2] 6 — 1 Year [3] 2 — 5 Years
#104 Do you share this toilet with neighbors?	[1] Yes [2] No
#105 Did you get this toilet from ACF?	[1] Yes [2] No [3] Other NGOs: Please state ......
#106 Is this toilet convenient during summer?	[1] Yes [2] No [3] If no, why? ......
#107 Is this toilet convenient during winter?	[1] Yes [2] No [3] If no, why? ......
#108 Could Styrofoam be used on seat during winter?	[1] Yes [2] No
#109 Could the toilet seat be adjusted for convenience?	[1] Yes [2] No [3] If Yes, [3a] Low [3b] High

#110 Does your door has a padlock for privacy and security?	[1] Yes [2] No
#111 What do you apply after defecation?	[1] Ash [2] Saw dust [3] Toilet paper [4] Others ......
#112 Do you know why you apply ash / sawdust / paper / etc. after defecation?	[1] Yes [2] No [3] If yes, state ......
#113 Do you still use your old pit latrine either in summer or winter?	[1] Yes [2] No [3] If yes state ......
#114 Do you prefer this toilet to your old pit latrine?	[1] Yes [2] No
#115 In your own opinion, could there be any way to improve this toilet in terms of design, convenience and accessibility?	State ......
#116 Can you recommend this toilet to your neighbor?	[1] Yes [2] No

2. Collection

#201 How often is your toilet filled up?	[1] 1 Month [2] 2 Months [3] 3 Months [4] 4 — 12 Months
#202 At what interval do you empty the toilet?	[1] 1 — 2 month [2] 3 — 5 months [3] 6 — 11 months [4] Yearly basis
#203 How do you empty the full toilet?	[1] Manual emptying [2] Mechanical vacuum tanker [3] Others
#204 Does ACF help to empty your full toilet?	[1] Yes [2] No [3] Other NGOs ......
#205 Do you pay for this service?	[1] Yes [2] No [3] If yes, how much ...... MNT/service?
#206 If Question #205 is 'No', will you be willing to pay for the service?	[1] Yes [2] No [3] If yes, how much ...... MNT/service?
#207 What do you do when the toilet filled up and emptiers are not available?	[1] Open defecation [2] Defecating around the toilet [3] Get another container for defecation [4] Don't know what to do
#208 Do you have an emptier contact number to inform him/her when your toilet gets full?	[1] Yes [2] No

3. Operation/Maintenance/Cost

#301 Have you taken part in any sanitation programme / activities on how to maintain toilets?	[1] Yes [2] No
#302 What time schedule you do observe to clean your toilet?	[1] Daily [2] Weekly [3] Fortnight [4] Monthly
#303 Are you facing any technical diffculties during cleaning?	[1] Yes [2] No [3] If yes, please state ......
#304 During summer, are you disturbed with any of the following? *(Choose all applicable)*	[1] Smell [2] Flies [3] Maggot [4] Others ......
#305 What do you think about the maintenance of this toilet?	[1] Too difficult [2] Difficult [3] Moderate [4] Not difficult
#306 What is your opinion on maintenance cost?	[1] Too expensive [2] Expensive [3] Moderate [4] Not expensive
#307 If your toilet collapsed, what will you do?	[1] Rebuild by myself [2] Get another one from the supplier [3] Use my old pit latrine [4] Use my neighbor's own

#308 What do you think are the reasons for this collapse?	[1] Poor workmanship [2] Low quality of constructing materials [3] Poor maintenance [4] Heavy wind blow / Rain
#309 Where exactly you mostly do encounter problems?	[1] Seat [2] Ventilation pipe [3] Urine diverter [4] Faeces collecting bucket [5] Other ......
#310 Are you willing to buy another toilet if the previous one collapsed or you move to a new site?	[1] Yes [2] No
#311 What do you think of the price if the toilet is sold for 1 million MNT?	[1] Too expensive [2] Expensive [3] Moderate [4] Not expensive
#312 How much do you think you can afford to get this toilet without subsidy?	MNT/Toilet: ......

ANNEX: SAMPLE QUESTIONNAIRE 3

CUSTOMER SURVEY OF GREYWATER SYSTEM

Questionnaire for customers about greywater management N°......

Part 1: General profile

Date:		
1. Respondent's gender:	◻ 1.1 Male	◻ 1.2 Female
2. Address: District ...... Khoroo	Subkhoroo......	Street......
3. Respondent's family status:	◻ 3.1 Husband ◻ 3.2 Wife ◻ 3.3 Child ◻ 3.4 Grandfather ◻ 3.5 Grandmother	
4. Respondent's age:	◻ 4.1 (18 – 24) years ◻ 4.2 (25 – 34) years ◻ 4.3 (35 – 49) years ◻ 4.4 (50 – 69) years ◻ 4.5 (70) years and over	
5. How many persons living in your household?		
6. Do you know you neighbors?	◻ 6.1 Yes ◻ 6.2 No	
7. Would you help you neighbors if required?	◻ 7.1 Yes ◻ 7.2 No	
8. What kind of soil is in your khashaa?	◻ 8.1 Rocky ground	
	◻ 8.3 High ground water level ◻ 8.2 Dry normal ground ◻ 8.4 Don't know	
9. Does your area flood during rain?	◻ 7.1 Yes ◻ 7.2 No	
10. What kind of cleaning products do you use for laundry, hand washing, cleaning the house and washing dishes and what is your average usage per month? *(Multiple choice)*	◻ 10.1 Bleach kg/l/pc ◻ 10.2 Baking soda kg/l/pc ◻ 10.3 Disinfectants kg/l/pc ◻ 10.4 Dish liquid kg/l/pc ◻ 10.5 Dish powder kg/l/pc ◻ 10.6 Glass cleaner kg/l/pc ◻ 10.7 Liquid soap kg/l/pc ◻ 10.8 Laundry powder kg/l/pc ◻ 10.9 Soap kg/l/pc ◻ 10.10 Others, specify ...... kg/l/pc	

11. How do you wash your laundry?	☐ 11.1 Hand washing ☐ 11.2 Washing machine
12. Where do wash u clothing?	☐ 12.1 Home ☐ 12.2 Neighbors ☐ 12.3 Water kiosk ☐ 12.4 Other ......

13. How many times per two weeks do you washing laundry?

	Times per 2 Weeks
13.1 Cold season	......
13.2 Warm season	......

Part 2: Current situation regarding greywater management

14. Do your collect rainwater?	☐ 14.1 Yes ☐ 14.2 No
15. Where do you dispose your grey water?	☐ 15.1 Pit latrine ☐ 15.2 Ecosan toilets ☐ 15.3 Soak pit ☐ 15.4 Wherever inside hashaa ☐ 15.5 Wherever outside hashaa ☐ 15.6 Other, specify ......
16. Who is currently in charge of disposing off the grey water?	☐ 16.1 Mother/Grandmother ☐ 16.2 Father/Grandfather ☐ 16.3 Daughter (Younger 15) ☐ 16.4 Son (Younger than 15) ☐ 16.5 Other, specify ......
17. How far you need to walk to dispose greywater?	☐ 17.1 Up to 5 m ☐ 17.3 10 – 20 m ☐ 17.2 5 – 10 m ☐ 17.4 More than 20 m
18. Why did you choose to dispose off the grey water like you do now?	☐ 18.1 No other choice ☐ 18.2 Always done like this ☐ 18.3 Convenient and quick ☐ 18.4 Taught that's alright

19. How many times a day do you go dispose your bucket with greywater?

	19.1 Laundry		19.2 Without Laundry	
	19.1.1 Cold season	19.1.2 Warm season	19.2.1 Cold season	19.2.2 Warm season
Times	......	......	......	......
How many buckets	......	......	......	......
Bucket size	......	......	......	......

20. Have you ever had any of the following problems while disposing off grey water?

Problems	20.1 No	20.2 Rarely	20.3 Often	20.4 Very often
20.1 Soak away full	......	......	......	......
20.2 Bad smell	......	......	......	......
20.3 Presence of flies	......	......	......	......
20.4 Dangerous (ice in winter time)	......	......	......	......
20.5 Very uncomfortable (getting wet, cold in winter)	......	......	......	......
20.6 Have to do it too frequently	......	......	......	......
20.7 Health problems	......	......	......	......
20.8 Pit latrine full	......	......	......	......
20.9 Ecosan toilet full	......	......	......	......
20.10 Others, specify	......	......	......	......

Soak Pit

21. If you have a soak pit, when do you use it?	☐ 21.1 Summer time only ☐ 21.2 All year long ☐ 21.3 Winter time only ☐ 21.4 Never
22. If you don't have a soak pit, why?	☐ 22.1 No space ☐ 22.2 No problem to use pit latrine ☐ 22.3 No money ☐ 22.4 Shallow ground water level ☐ 22.5 Rocky ground ☐ 22.6 Don't know ☐ 22.7 Other, specify ......
23. Consideration to improve the soak away?	☐ 23.1 Yes ☐ 23.2 No

Water Reuse

24. For which purpose and in which chronology do you use/reuse water?

Purpose	Chronology
24.1 Washing clothing	
24.2 Washing dishes	
24.3 Personal care	
24.4 Irrigation	
24.5 Cleaning house	
24.6 Others, specify	

Part 3: Preferences needs and demands

25. Are you satisfied with you current practice dispose greywater situation?	☐ 25.1 Yes ☐ 25.2 No

26. What is important for you and your family, please rank it by priority/importance?

Needs	Ranking
26.1 Education for children	......
26.2 Water sanitation (Improving toilet and greywater treatment)	......
26.3 New car	......
26.4 Computer, TV, smartphone	......
26.5 Health	......
26.6 Other, please specify	......

27. Do you think it is important to treat grey water before disposal?	☐ 27.1 Yes ☐ 27.2 No
28. Why do you think it is important to treat grey water before disposal?	☐ 28.1 Sanitary reasons ☐ 28.2 Regulation reasons ☐ 28.3 Environmental reasons ☐ 28.4 Health reasons ☐ 28.5 Other, specify

29. What kind of advantages would be important for your by use of a greywater treatment and disposal system?

Advantages	Ranking
29.1 Close to or inside the house	......
29.2 Price	......
29.3 No smell	......
29.4 Easy to maintain and	......
29.5 Separated from toilets pit (filling up less quickly)	......
29.6 After treatment water use	......

30. Are you interested and would you like to install an a grey water treatment and system? (If not, continue with question N° 31)	☐ 30.1 Not ☐ 30.2 Less interested ☐ 30.3 Interested ☐ 30.4 Very interested
31. Would you be willing to provide space and how much?	☐ 31.1 1 – 10 m² ☐ 31.2 10 – 20 m² ☐ 31.3 20 – 30 m² ☐ 31.4 30 – 40 m² ☐ 31.5 No
32. Do you have a garden at home?	☐ 32.1 Yes (Continue with question N° 34) ☐ 32.2 No (Continue with question N° 33)
33. Why not?	☐ 33.1 I don't know how ☐ 33.2 No time ☐ 33.3 No space ☐ 33.4 Don't like vegetables ☐ 33.5 Easier to buy it ☐ 33.6 No tools ☐ 33.7 No seeds
34. Would you like to grown you own vegetables?	☐ 34.1 Yes ☐ 34.2 No

Part 4: Ability to pay and decision making

35. How much is your household's monthly income?	☐ 35.1 Up to 140.000 MNT ☐ 35.2 140.400 – 280.000 MNT ☐ 35.3 280.000 – 550.000 MNT ☐ 35.4 550.000 – 750.000 MNT ☐ 35.5 750.000 MNT and over
36. Would you be ready to invest for greywater treatment (means pay amount every month for 2 years?)	☐ 36.1 Yes ☐ 36.2 No
37. What is the maximum possible price you would be willing to pay in a month for 2 Years? (Meaning: only for the installation and material cost of the solution)	☐ 37.1 92.000 – 115.000 MNT ☐ 37.2 45.000 – 92.000 MNT ☐ 37.3 22.000 – 45.000 MNT ☐ 37.4 10.000 – 22.000 MNT ☐ 37.5 No, too expensive
38. Are you ready to share installation cost and maintenance cost with neighborhood, to save money?	☐ 38.1 Yes ☐ 38.2 No
39. If not, could you please explain why?	......
40. Would you provide space in your Kashgar for treatment system to use it with your neighbors and get paid for it?	☐ 40.1 Yes ☐ 40.2 No
41. Who in your family / household takes decisions about improvements in your khashaa?	☐ 41.1 Mother/grandmother ☐ 41.2 Father/grandfather ☐ 41.3 Others, specify

Part 5: Communication channels

42. Where would you go to look for information about new housing technologies?	☐ 42.1 Newspapers/magazine ☐ 42.2 Home visits ☐ 42.3 Neighbors ☐ 42.4 Television ☐ 42.5 Internet ☐ 42.6 Advertising in public places (Bus stop, shop) ☐ 42.7 Friends/family ☐ 42.8 No information
43. How do you prefer to receive the information about new housing technologies?	☐ 43.1 Newspapers/magazine ☐ 43.2 Home visits ☐ 43.3 Television ☐ 43.4 Internet ☐ 43.5 Advertising in public places

QUESTIONNAIRE RELATED TO KAP SURVEY

Social Capital

1. How much do you know about your neighbour?
   a. A lot   b. Some   c. Little   d. None
2. Can you get some help from your neighbours when you need?
   a. Yes   b. No
3. If yes, how much do you get help (Either monetary or non-monetary)?
   a. A lot   b. Some   c. Little   d. None
4. Do you have any relatives around you or in the city or in the ger areas?
   a. Yes   b. No

General Questions

1. How would you like to recommend to improve the current situation in the Ger areas?
   a. A good toilet/eco-toilet,   b. Water connection to Gers
   c. Apartment building,   d. Sewerage system
   e. Awareness raising   f. Proper emptying service
   g. Others
2. How much do you interested to use the treated greywater?
   a. Not interested   b. Less Interested   c. Interested   d. Very interested.
3. Are you willing to use treated greywater?
   a. Yes   b. No   c. I don't know
4. Are you willing to consume the products produced by treated greywater?
   a. Yes   b. No   c. I don't know

ANNEX: 作者简历及在学研究成果

一、作者入学前简历

起止年月	学习或工作单位	备注
1999年8月至2003年8月	在National University Bangladesh生物工程攻读学士学位	
2006年7月至2009年7月	在 Bangladesh University of Engineering and Technology, Bangladesh 工业生物工程攻读硕士学位	
2009年10月至2011年9月	在 Nagoya University, Japan 工业生物工程攻读硕士学位	

二、在学期间所获的科研奖励

1. Nominated for USTB President Gold Medal 2015.
2. Received 1st Winner Prize of USTB International Excellent Student Award, 2013 – 2014.
3. Project Manager under joint research project of USTB and Action Contre la Faim (ACF) International France and Mongolia.
4. Received International PhD Scholarship from ACF International France.
5. Elected as Chairman of Nagoya University Global Environmental Leaders Association, Japan from 2012 – present.
6. Winner of photo contest on the PhD study area photo by the Nagoya University, Japan in 2012.
7. Invited as 'Visiting Research Scholar' by the University of West of England, Bristol, United Kingdom.
8. 'Research Trainee' of McGill University, Canada since 2014.
9. Research Trainee/Researcher, The University of Auckland, New Zealand since 2011.
10. Principal Investigator of a joint research project by The University of Auckland and Massey University in New Zealand.
11. Ambassador of WEDC. Loughbourough University, UK.
12. Selected as Panalist at the World Water Forum 2015, Korea.
13. Supervised 7 international master's students.

AS FIRST AUTHOR

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