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Opportunities and challenges for greywater treatment and reuse in Mongolia: lessons learnt from piloted systems

Sayed Mohammad Nazim Uddin, Zifu Li, Heinz-Peter Mang, André Schüßler, Tobias Ulbrich, Elisabeth Maria Huba, Eric Rheinstein and Jean Lapegue

ABSTRACT

In Mongolia, as worldwide, communities are challenged by water scarcity, depletion and pollution. Greywater treatment and reuse could partially meet water demand and help protect the environment and health. In March 2010, greywater from six randomly sampled households in the Ger areas of Ulaanbaatar, Mongolia, was analyzed followed by the development of three innovative treatment systems: an underground (UG-), greenhouse (GH-) and ice-hole greywater treatment unit (IH-GWTU). The UG- and GH-GWTU were implemented to identify opportunities and challenges for future investments in greywater treatment and reuse. Users' and non-users' perceptions, and business opportunities, were assessed. Laboratory analysis showed a high chemical oxygen demand (6,072–12,144 mg/l), N-NH_4^+ (183.7–322.6 mg/l), PO_4^- (12.6–88.2 mg/l) and total suspended solids (880–3,200 mg/l) – values exceeding the WHO guidelines and much higher than in any other country: low water consumption combined with traditional diet might be major reasons. Odourless and colourless water after treatment in a UG-GWTU lead to more acceptance than a GH-GWTU. Business opportunities include the use of treated water for irrigation, considering WHO and national standards. Further research focuses on seasonality of installation, technical shortcomings, maintenance, biological quality control and user training.

Key words | Ger area, greywater treatment, groundwater pollution, peri-urban areas, reuse, water scarcity

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INTRODUCTION

Global water stress and scarcity, depletion and pollution in high, middle and low income countries have been addressed in many studies (see for instance, Postel 2000; Exall *et al.* 2006). A growing number of contaminants are entering water bodies due to anthropogenic activities (Montgomery & Elimelech 2007), which may dramatically reduce the amount of potable water on earth. Greywater definitions and characteristics are well documented in a range of studies (see for instance, Jeppesen 1996; Ghaitidak & Yadav 2013); treatment and reuse can be one potential option to solve the problem of reuse for different purposes which are the source of a large portion (50–80%) of domestic wastewater generation (Li *et al.* 2003; Abusam 2008). Jeppesen (1996) revealed that 30–50% water can be saved at household level, if all greywater is reused after some sort of treatment. 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 (Li *et al.* 2009; Chen *et al.* 2013a, 2013b). 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 water shortage, minimize health hazards, conserve the environment and

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reduce environmental risks (Jeppesen 1996; Jenssen et al. 2005; Domenech & Sauri 2010). There might be various challenges to treat and reuse greywater in various climatic zones (see for instance, Exall et al. 2006). To fulfil 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.

Mongolia, where this study was conducted, claims the coldest capital in the world, with an annual mean temperature of $-3.7\,^{\circ}$C (Hauck 2008). The country has one of the lowest rates of access to improved sanitation and major parts of the population rely on only very poor quality water (UNICEF 2010). The country faces numerous natural disasters such as drought, heavy rainfall, flood, snow and storms, and extreme cold and heat (Batimaa et al. 2010), which without doubt have a great impact on water resources, either directly or indirectly. Ulaanbaatar, the capital of Mongolia, has a population of over one million and is experiencing many environmental, health and socio-economic problems (World Bank 2010; Nriagu et al. 2012). Sixty percent of the total population of Ulaanbaatar reside in peri-urban informal settlements, called Ger areas. A lack of safe water supply and unimproved sanitation have been found to be the key issues in the Ger areas of Mongolia where simple, unimproved and unventilated pit latrines (UNICEF 2010; World Bank 2010; Sigel et al. 2012) and soak pits are generally used for on-site sanitation and household greywater, resulting in unhygienic living conditions. Water in the Ger areas is mainly provided by over 550 public water kiosks where the average water consumption is 10 litres/person/day (l/p/d) (World Bank 2010).

Mongolia is one of the 60 countries in the world with limited water resources, significantly lower than the world average (Batimaa et al. 2010). Additionally, both surface water, for example the Tuul River, and groundwater quality is degrading due to numerous anthropogenic activities (Batsaikhan et al. 2011; Nriagu et al. 2012). It has been projected by the CSIRO-Mk2b model of the Tuul River that water resources will decrease by up to 25% by 2080 due to climate change impact (Batimaa et al. 2010). Limited capacity in water resources and their treatment, and the limited sewerage system have been identified as major constraints for increased demand in future (World Bank 2010). Moreover, Mongolian water resources are under threat of climate change and rapid urbanization with over 50% of the population facing challenges to obtain access to clean water (Batimaa et al. 2010). Surface water is iced for over half the year during the long winter and underground water is polluted by uranium in some areas of Ulaanbaatar (Nriagu et al. 2012). Protection of existing water resources is urgently required, such as treatment and reuse of greywater for non-potable purposes at the household level, in order to cope with water demand and to overcome (to some extent) water-related challenges in the future. This study is the only study on household level greywater treatment and reuse in Mongolia in the literature, and was conducted jointly by a team from the University of Science and Technology Beijing (USTB) with the field cooperation of Action Contre la Faim (ACF) Mongolia, funded by ACF International under a research project on 'sustainable sanitation for the vulnerable peri-urban population in Ulaanbaatar, Mongolia' since 2011 in the Ger area of Ulaanbaatar. It identifies possible opportunities and challenges for treatment of greywater and the ensuing reuse options. The perceptions of both users and non-users on greywater treatment and reuse were assessed for the future acceptability and scale up of the technology.

MATERIAL AND METHODS

Study area and site selection

The study area was made up of the peri-urban Ger areas, informal and unplanned settlements, which surround Ulaanbaatar City in Mongolia. Figure 1 shows the study area map.

From 17 pre-selected sites, 13 sites were evaluated as potential sites for the installation of model greywater treatment units (GWTU) based on several criteria, for instance, availability of space, people's interest, technological suitability and opportunity to reuse the treated greywater on or nearby the compound. Some households were already participating in the water, sanitation and hygiene programme of ACF Mongolia. Other sites were visited by request of the owners who contacted ACF staff during an

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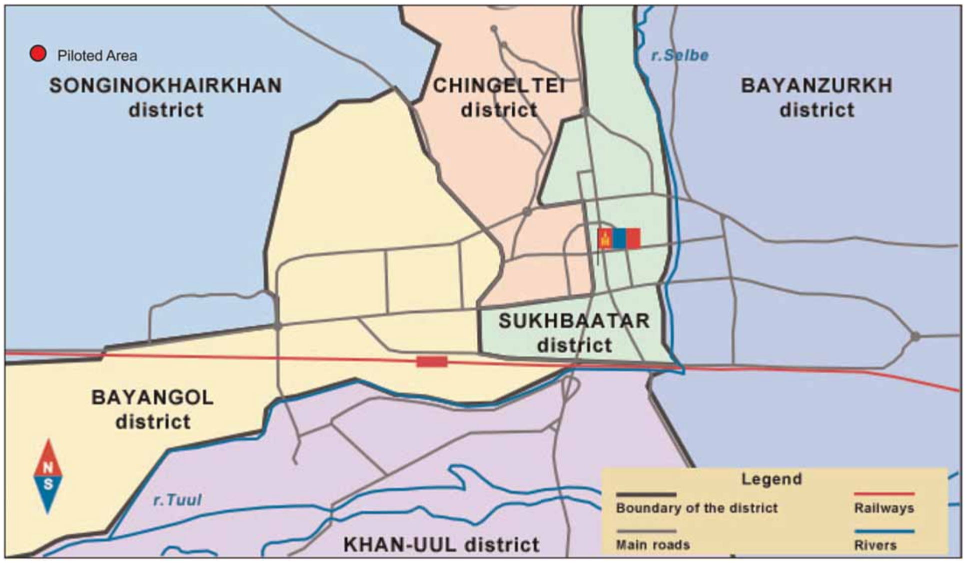

Figure 1 | Ulaanbaatar city and study area.

information session in the community. The most suitable compounds were selected from those sites to pilot two of the proposed greywater treatment units. The following criteria were applied to 'scout' potential GWTU sites for on-site 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 agricultural farms or golf courses.

Sample collection and laboratory analysis

The USTB team distributed six barrels, each of 60 litre volume, to collect greywater samples from six randomly sampled households in the Ulaanbaatar Ger area. The analysis was carried out at the USTB laboratory in Beijing, China, in March 2010 to get to know the characteristics of household greywater in the Ger areas. The methodology of analysis followed the relevant ISO standard. The samples from this mixed household greywater contained hand-washing, kitchen and laundry greywater. Each of the six sampled households collected its mixed greywater for one entire day in the 60 litre bin. Table 1 shows the samples collected from the six households.

Model development and piloting

Three different concepts and technical models of greywater treatment were developed by USTB and ACF Mongolia considering the high concentration of greywater and extreme cold climatic conditions. These concepts and models include an underground greywater treatment unit (UG-GWTU), a greenhouse greywater treatment unit (GH-GWTU), and an ice-hole greywater treatment unit (IH-GWTU) (Figure 2). Two of them were applied at

Table 1 | Socio-economic data of Ger area households who supplied the greywater samples

Barrel Number	Number of Children	Number of Family members	Washing Machine	Volume of Greywater Sample (litres)	Laundry Water Included
1	4	10	Yes	30	Yes
2	4	7	Yes	20	No
3	2	5	Yes	30	No
4	2	4	Yes	20	No
5	2	5	Yes	20	No
6	3	11	Yes	40	No

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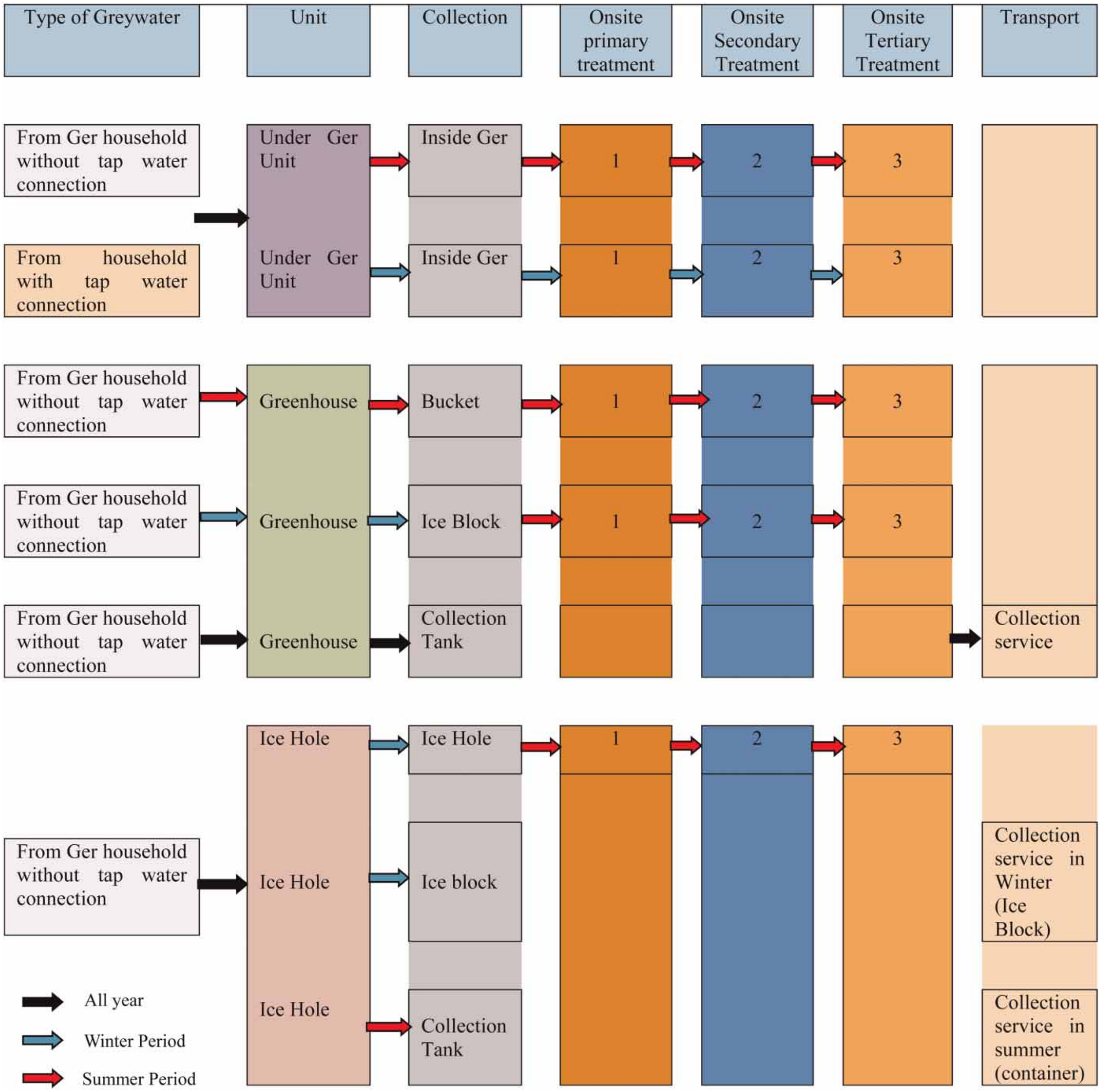

Figure 2 | Flow diagram of the three greywater systems (*Source:* Adopted from Schüßler 2011).

pilot scale in 2011 in Ger households to identify opportunities and challenges for future investments in greywater treatment and reuse options in the Mongolian context. The household owners, where the two units were piloted, and the concerned ACF staff were trained to carry out the piloting, operation and maintenance of the treatment units. The household owners were the key stakeholders and responsible for running the units to obtain more practical knowledge in the operation and maintenance of the units. The three models are described below.

Underground greywater treatment unit

Greywater is poured into a sink inside the Ger or the house. Below the sink a fat trap with screen is installed to retain fat and impurities. The screened greywater flows into a septic

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tank, which is located in an insulated chamber under the Ger or the house. Remaining fat and solid particles are retained. The pre-treated water leaves the septic tank towards a secondary treatment step, which is a vertical flow filter or an anaerobic filter. For the tertiary treatment step a slow sand filter, vertical flow filter or an anaerobic filter is recommended. A storage tank collects the treated effluent water, which could then be used for irrigation. As an option, a percolation bed could be installed below the chamber to recharge groundwater during wintertime when the treated water cannot be used or stored on site. The fact that the chamber is located under the Ger or house leads to positive temperatures inside the chamber throughout the whole year, and prevents the treatment unit from freezing during winter. Effluent water can be used for irrigation in summer; during winter the effluent water could be stored in the form of ice; so a huge amount of water will be on hand in springtime. It is also part of the pilot phase to empower GWTU users to handle the different treatment techniques: as the composition of the greywater is not 100% specified, the maintenance activities and intervals cannot as yet be specified in detail. From time to time, users of GWTU have to take sludge out of the septic tank and sand filter. Sludge can be taken to an on-site sludge drying bed where it is dried. Sludge could also be co-composted in an on-site compost pile.

Greenhouse greywater treatment unit

Greywater is supplied into the inlet of the treatment unit, where screening also takes place. The next step is a septic tank where solids and floating fat particles settle. After this pre-treatment in the septic tank, the greywater receives a secondary treatment in a vertical flow constructed wetland or an anaerobic filter. For the tertiary treatment, a slow sand filter is constructed. At the end of the treatment process, a tank is recommended for collection and storage of the effluent water, which can be used for irrigation. During winter it is not possible to achieve permanently positive temperatures inside the passive solar greenhouse so treatment is not possible. Therefore, it is recommended to store the raw greywater on site in the form of ice for 4 months (from December to March). When temperatures inside the greenhouse climb above 0 °C, greywater ice blocks are placed in the treatment unit where they melt and the liquefied greywater can be treated as described above. Effluent water can be used for irrigation.

An inside green house unit could be chosen if the soil is rocky thus making it difficult to dig. If the soil consists of gravel or scissile rock, the site might be considered for the construction of either an underground or an ice-hole unit design. Information about soil characteristics could be obtained by asking about the depth and the year of installation of the currently used pit latrine. Also, for winter greenhouse construction options, it is necessary to know the compound's West-East axis. Winter greenhouse construction may require changing the fence in order to minimize any shadow effect.

Ice-hole greywater treatment unit

The frozen greywater is brought to an insulated chamber which is installed underground, designed to receive a calculated amount of frozen greywater throughout the winter months. When outside temperatures climbs above 0 °C, the ice blocks are supplied to a treatment unit. The greywater melts and can be treated. The ice blocks inside the insulated chamber stay frozen until summer. During summer months, liquid greywater is applied directly to the treatment unit. The unit provides for an optional three-step treatment: (1) a septic tank for primary treatment; (2) a vertical flow constructed wetland or an anaerobic filter for secondary treatment; and (optional) (3) a slow sand filter for tertiary treatment. A collection and storage tank or pond is recommended to keep the effluent water for irrigation. Table 2 shows the hydraulic loading of major components of the three greywater treatment units.

Project evaluation

The project was evaluated by a team comprising USTB with the coordination of ACF Mongolia during the period of November and December 2012, in order to assess experiences and perceptions of users regarding both treatment units and reuse of greywater. Various business options and scopes for treated greywater utilization were also considered for future marketing of reusable greywater.

Questionnaires for semi-structured interviews were developed for the users of greywater, key informants and stakeholders to obtain data for this evaluation. An observational

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Table 2 | Hydraulic loading of the major components of each treatment unit

Treatment unit	Component	Hydraulic loading	Unit
UG-GWTU	Grease Trap	Daily flow	60 l/d
		Retention time	0.5 d
	Septic Tank	Retention time	5 d
	Aerobic Filter	Max. loading/m^2	0.4 m^3
	Slow Sand Filter	Max. loading/m^2	0.4 m^3
GH-GWTU	Septic Tank	Daily flow	60 l/d
		Retention time	5 d
	Anaerobic Filter	Max. flow at peak hours	5 l/d
	Slow Sand Filter	Max. loading/m^2	0.4 m^3
IH-GWTU	Septic Tank	Daily flow	119.4 l/h
		Retention time	5 d
	Distribution Chamber	Times of loading	5 times/d
	Constructed Wetlands	Max. flow at peak hours	23.9 l/h
	Collection Chamber	Daily flow	119.4 l/d
		Size of chamber	119.4 l/d

investigation was undertaken to identify current problems in Ger areas regarding the related issues of greywater disposal systems, sanitary infrastructure and drainage systems. The results from the Knowledge, Attitude and Practice (KAP) household survey, conducted by ACF Mongolia at the end of 2012 within 210 households in the Ger areas were used as supplementary information about the opinions of both users and non-users on greywater issues. The cluster sampling method was applied, due to the large population size and scattered households in the intervention area, under which a statistical accuracy of 10% precision was preferred. Households were randomly selected for the survey in each residential cluster. Additionally, a market survey was carried out to assess various kinds of products of soap and detergents, which are used by the Ger area residents.

RESULTS AND DISCUSSION

Current situation

The results from the KAP survey among the households of the Ger areas show that 51.4% households have a soak-pit in their compound to discharge greywater and 40% of households pour greywater into their pit latrines. The other households discharge greywater onto the roads, in the yard or in other places. The practice of Ger residents for discharging their greywater into pit latrines, soak-pits, yards and on the open streets causes 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 practise 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 behaviour 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 greywater in the compound or on the street, causing considerable ice hazards. As people maintain the same attitude in the warmer months this may considerably degrade the environment and provide favourable conditions for vectors to breed (WHO 2006).

Greywater characteristics

The laboratory analysis shows (Table 3) a high concentration of chemical oxygen demand (COD) (range from 6,072 to 12,144 mg/l), N-NH_4^+ (range from 183.7–322.6 mg/l), PO_4^+ (range from 12.6–88.2 mg/l) and total suspended

Table 3 | Test results of greywater from six randomly sampled households

Sample	COD (mg/l)	N-NH_4^+ (mg/l)	PO_4^+ (mg/l)	pH	TSS (mg/l)
1	11,334	322.6	88.2	6.23	1,280
2	6,072	183.7	16.2	5.29	1,720
3	12,144	205.4	18.6	6.00	3,200
4	7,286	195.6	12.6	5.56	880
5	6,882	282.9	52.2	6.02	1,720
6	6,477	289.5	49.4	6.38	1,300

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solids (TSS) (range from 880to 3,200 mg/l) which are much higher than in any other country (Li et al. 2003; Ghaitidak & Yadav 2013). The values are much higher than the values mentioned in the WHO (2006) guidelines (e.g. COD is 366 mg/l, TSS is 162 mg/l and N-NH_4^+ [1.7]mg/l). In addition, the average greywater generation in the Ger area households was 4 l/p/d with an average range of water consumption of 8–10 l/p/d (World Bank 2010). The greywater generation is much lower in the Ger areas than in other countries, such as 66 l/p/d in Jordan and 70 l/p/d in Germany (see, for instance, Li et al. 2003; Palmquist & Hanaeus 2005; Ghaitidak & Yadav 2013).

The results from the KAP survey among the residents of the Ger areas confirm that over 90% of households practise the intensive use of detergents for washing their clothes, 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 (Carpenter et al. 1998; Batsaikhan et al. 2011). Moreover, this practice may threaten the water supply security (Wu & Chen 2013) in the study area. Limited water consumption (8 l/p/d during winter), same water usage for different purposes, higher/intensive usage of chemical detergents, diet and cooking methods that contain much fat, milk and oil, and modern lifestyle may 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) as being highly influential on the characteristics of greywater.

The concentration of COD in mg/l has a 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 sample No. 1 is due to the washing powder used for laundry purposes. Considering laundry services, one family could produce a fertilizer value of up to 1 kg of phosphate annually from nutrients contained in the greywater.

A market survey was carried out by Schüßler (2011) and showed that in Mongolia the major products of the 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 colour brighteners. Dishwashing detergents come in powder, liquid, gel and tablet form. Soap comes in bars or liquid form. These characteristics of chemical washing products may have a great influence on the high values of the 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 the authorities that could take a lead in this field are already in place, among them being 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.

Suggested greywater treatment units

Various types of greywater treatment systems have been addressed (Ghaitidak & Yadav 2013), which have been developed and piloted in many low, middle and high income countries. For this study, several facts were considered to establish sustainable and affordable greywater treatment systems in the Ger areas at household level. These include the cold weather: temperatures drop under −40 °C, freezing soil down to a 3.5 m depth during the months of November through to May (6–7 months per year) and no sewer connection, neither in the compounds nor in the streets in the near future. The greywater treatment units were developed based on the requirements to be convenient for maintenance, economically feasible and affordable for low income Ger residents, and technologically suitable under extremely cold climatic conditions. Additionally, the availability of construction materials for each greywater treatment unit (GWTU) was considered in order to facilitate its replication.

Underground greywater treatment unit

Field investigation revealed that some households have a storage chamber under their Ger or house where they keep vegetables during winter to protect them from freezing. These storage rooms maintain temperatures above freezing point. This space might reduce the cost of excavation for the installation of an UG-GWTU. The fact that the chamber

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is located under the residence leads to temperatures always above zero inside the chamber, and the GWTU could continuously operate throughout the year without any effect from cold temperatures.

Greenhouse greywater treatment unit

The GH-GWTU was identified as the technology option with the most advantages. However, this treatment option combined with an above ground storage tank was evaluated as not being practicable. The unit for a house with water connection seems to be practicable, but building a constructed wetland of 4 m depth causes concerns. The proposed GH-GWTU to treat greywater was modified according to the experience of the NGO GERES with passive solar greenhouses in Mongolia.

For any off-site treatment (greywater is not treated at the source of origin but 'centralized' in an indoor greenhouse unit) a collection service is requested to transport greywater from several households to the treatment unit. Part of the pilot phase is also to empower GWTU users to handle the different treatment techniques: as the composition of the greywater is not 100% specified, the maintenance activities and intervals could also not yet be specified in detail. From time to time users of GWTU have to remove sludge from the septic tank and sand filter. Sludge could be brought to an on-site sludge drying bed. Sludge could also be composted in an on-site compost pile. Fat can be burned on site together with solid waste (currently a common practice, although not really recommended) or could be used as fuel for the oven inside the Ger, if the stove is suitable and no liquid fat can drop out.

Piloting and evaluating the GWTUs

UG-GWTU

The summer period for construction is very short in Mongolia (June–October) and all types of construction have to be completed within this period. The UG-GWTU was set up for piloting during that period in 2011. The results from interviews with users show that the system was running without any problems for the first two months and then it was running slower until it clogged completely. The slow sand filter was identified as the component with the biggest blockage due to the high grease and fat content of the greywater. In October 2011, the UG-GWTU was dismantled and removed by the owner of the house. The chamber is currently being used as a storage room. The chamber underneath the house was warm enough to keep the water unfrozen even during the month of November when the temperature outside was recorded as $-39\,^{\circ}$C. Above that, smell and odour were mentioned to be intense from the system, but only towards the end of the operation of the system. No maintenance was applied except for removing grease two or three times per month, and cleaning the sink twice a month. The fat and grease were disposed of with the household garbage. Sludge was not recovered. To overcome the clogging, chemicals were applied, but no improvement resulted from that intervention due to lack of information about the adequate maintenance measures, as well as inadequate handling guidelines.

GH-GWTU

At the end of summer 2011 the installation of the GH-GWTU was completed by ACF. The system was running for around 1 month, but after 2 weeks it started to become clogged due to heavy grease and fat content. After 4 weeks the gravel filter and the slow sand filter were overflowing. The system was cleaned and emptied shortly after by the user, and then stopped running. Both filters were described to have a thick layer of sludge on top. In the end, water was overflowing from the system and a very strong smell developed. Even with the additional aeration that was installed afterwards, the smell was described to be so intense that it could be noted in the Ger next to the greenhouse. The owner decided finally to dismantle the unit. It should be mentioned that the owner was not provided with guidelines on maintenance apart from washing the gravel in the case of blocking. On clogging, the user cleaned the system, but even after this the outcome was described as unsatisfactory. The remaining grease and sludge was disposed of with the household garbage. The user expressed the view that the frequent cleaning of the unit (e.g. washing the gravel, etc.) was regarded critically since it takes a lot of work and time and involves a lot of effort.

The treatment capacity of both UG-GWTU and GH-GWTU is 60 litres/day. The average daily production of

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greywater is 20 litres/household which leads to an annual production to 7,300 litres/household. The systems are feasible in terms of greywater production at household levels. As the UG-GWTU can run throughout the year, there is no need to store the greywater during the winter period. However, greywater needs to be stored for the GH-GWTU during the extreme winter/freezing period.

Perceptions of users and non-users

The perceptions of greywater treatment and reuse options, except for some maintenance and technological issues, were well understood by 100% of users of greywater. Based on the physical characteristics of the treated greywater, the UG-GWTU was more acceptable than the GH-GWTU, because of the odourless and colourless water from the UG-GWTU. Although the users of GH-GWTU did irrigate the treated greywater to their vegetable plots and produce lettuce, cucumber and tomatoes, it did not meet with user satisfaction due to its strong odour and yellow colour. However, all users generally accepted the treated greywater from both units, which indicates that improved models could be scaled up to meet part of the water demand in the Ger areas. Business opportunities were assessed including the application of treated greywater as irrigation water for gardening (which is in great demand from the Ger residents), for other horticultural applications and many more.

KAP survey results (Figure 3) show that the perception of greywater reuse among non-users was well accepted by almost 50% of the respondents. They had a willingness to use the treated greywater and to consume agro-commodities produced with it. One third of respondents did not have any knowledge at all of greywater treatment and reuse issues. The rest of the respondents had a negative approach to this issue. As greywater treatment and reuse is completely new for Ger residents, low awareness and knowledge levels, and social acceptance are still challenges for scaling up of the technology. Additionally, the survey results show that most respondents had a very low awareness level of the greywater treatment and reuse issue, organic food consumption, use of bio-degradable detergents and other environmental issues.

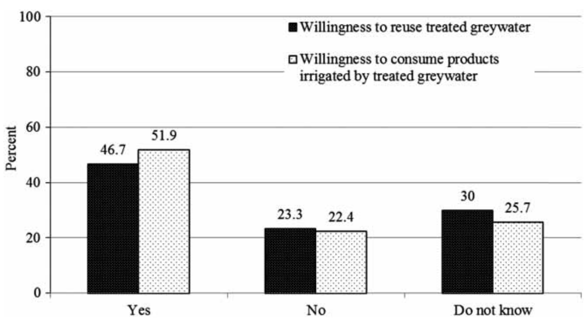

Figure 3 | Non-users' willingness to reuse treated greywater.

Opportunities and challenges for greywater treatment and reuse

There are a range of opportunities and challenges for treating and reusing greywater in the Mongolian context, and these are listed in Figure 4. Maintenance problems were identified as one of the challenges in both the United States and Australia where 60–80% of 'on-site domestic wastewater treatment plants' were not maintained sufficiently (Jeppesen 1996). This study also addressed several challenges regarding the period of installation, technical shortcomings and maintenance. These challenges, which need to be further researched, include clogging of the systems, strong odour from the treatment units, lack of maintenance, unskilled human resources, lack of user guidelines, lack of ultimate disposal of fat and grease produced from the units, and lack of sludge removal. Local socio-economic and climate conditions pose additional challenges, which obviously are not yet completely answered by the piloted models, such as the temperature dropping under $-40\,^{\circ}C$, freezing soil down to 3.5 m depth for up to 8 months per year, low income, and a low level of technical skills for operation and maintenance.

The way forward

Further technical modifications of the piloted models and detailed and specific training of the users should make the technology fit in to the socio-economic and ecological context. Regarding the GH-GWTU, the design would benefit from adjustments such as introducing a grease trap as a pre-treatment, a ventilated system for gas/odour evacuation, replacement of the metal barrel with plastic or pre-fabricated

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Opportunities

Technological

- 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.
- Reduction in 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.

Challenges

Technological

- Clogging of the systems.
- Strong odour from the units.

Operation and Maintenance

- Lack of maintenance.
- Unskilled/low level of technical skilled human resources.
- Lack of user guidelines.
- Lack of ultimate disposal of fat and grease produced from the units.
- Lack of sludge removal.

Climatic

- Temperature drop under -40°C.
- Freezing soil down to 3.5m depth for 6 to 7 months per year.

Social

- Low awareness on this issue.
- Social acceptance of all Ger residents.

Economic

- Low income people.
- Low interest from Government.

Institutional

- Low capacity, low training skill.
- No policy.
- Low political willingness.

Figure 4 | Opportunities and challenges for greywater treatment and reuse in Mongolia.

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barrels, and pipes to allow overflow. Furthermore, the system needs to be maintained and cleaned frequently for effective operation. The greywater from the Ger areas is known to be highly concentrated since it is used repeatedly and traditional food contains a lot of fat. For this reason it is strongly recommended to have a two chamber grease trap installed before releasing the water into the septic tank. To overcome the effect of the cold climate on the treatment processes and efficiency, greywater only needs to be stored in front of the system for the GH-GWTU. The UG-GWTU can run throughout the year for treatment without any impact from cold temperatures. As both water consumption and production are low in the study area, the treatment capacity of both systems is feasible and it is recommended to store greywater for GH-GWTU during the extreme winter and treat the frozen greywater as soon as the temperatures move above freezing. Compared to the UG-GWTU, the GH-GWTU is easy accessible and it is suggested that the GH-GWTU be used as a pilot again with adjustment. The IH-GWTU which has been briefly described above can be considered in the Ger area context during winter when greywater freezes. Both the upgraded GH-GWTU and the IH-GWTU would be feasible in the study area and beyond.

Other technological options such as 4-in-1 biogas systems, willow wastewater treatment facilities and septic tanks with perforated pipe soil filters may also offer a high potential for adaptation to Ger area conditions. As the period for construction is very short in Mongolia (4–6 months in a year), it is proposed that the planning and design be done before that period. A laboratory analysis after treatment is suggested to assess the potential and suitability of the greywater treatment technology, and to reuse them in various sectors according to international standards of greywater reuse.

An overall approach foresees that the design of the GWTU should be in line with the desired effluent quality for the intended pathway, disposal or reuse. In the case of Mongolia, there are as yet no regulations for the use of reclaimed water. Since official standards for reuse for irrigation are not yet established, treated greywater should meet the standards provided by the WHO guidelines (WHO 2006). A legal framework or guidelines on greywater can be supported based on the complete piloting of the proposed GWTUs in future. In addition, a high level of advocacy tools concerning pollution and preservation of resources in relation to future greywater treatment and reuse should be developed to involve the government as an active role player at policy level. There are no policies or guidelines at present in Mongolia on the greywater treatment and reuse option due to a lack of political willingness. This study and the proposed piloting would therefore trigger policy making on this issue. Additionally, there might be the possibility of up scaling the household level GWTUs to get rid of greywater in non-connected Ger areas, which might prevent the environmental pollution and health hazards associated with greywater produced and discharged there contribute to the global knowledge of the sector on the management and reuse of greywater in cold climate conditions.

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