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Assessment of Alternative Sanitation Systems in the Navin Well-Field Project Area, Herat, Afghanistan

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ABBREVIATIONS

CW	constructed wetland
DACAAR	Danish Committee for Aid to Afghan Refugees
DEWATS	Decentralised wastewater treatment system
DoUD	Department of Urban Development
EP	equivalent population
ESF	Ecosan Services Foundation
FWS	free water surface
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HF	horizontal flow
IWA	International Water Association
SSF	subsurface flow
ST	septic tank
SuSanA	Sustainable Sanitation Alliance
UDDT	urine-diverting dehydration toilet
UNICEF	The United Nations Children's Fund
VF	vertical flow
VWO	Voice of Women Organisation
WECF	Women in Europe for a Common Future
WHO	World Health Organisation

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ABSTRACT

The Navin Well-Field Project Area is the source of water supply for Herat City. The existing sanitation systems in the well-field area pose a threat to the groundwater quality and hence to the water source of the city. The goal of the GTZ-Rodeco project interventions in sanitation in the Navin Well-Field Area is to protect the water supply source of Herat city from contamination. To this end, an assessment was carried out in the project area to identify suitable alternative sanitation systems for 42 target households that lie within 70 m of the deep water wells.

The household sanitation systems in the area are basically of two types. The most common system is a so-called 'simple latrine', which is an above-ground raised vault and excreta are dropped through a hole and collected in the vault. The bottom base is open ground and liquid gathered in the vault can flow into the soil and ground water. These latrines have to be emptied out regularly, which is mostly done manually. The other sanitation system is a pour-flush toilet connected to an underground, off-set sewage well. This soakage well is not very deep and also has to be emptied out regularly, mostly by a tanker.

The criteria used to select alternative sanitation systems for the project area were as follows: ground water protection, health safety, localised systems, no odour, no flies, operation and maintenance possible by the households, locally adaptable, and possibility of productive sanitation (reuse).

Four sanitation systems were selected based on the criteria, which were as follows:

1) Double vault urine-diverting dehydration toilet system (UDDT)
2) Fixed-dome biogas sanitation system
3) Constructed wetland wastewater treatment system
4) Septic tank with off-site subsurface infiltration wastewater treatment system

The first two systems treat the toilet waste whereas the latter two treat the combined wastewater (i.e. including greywater) of a household. The first three systems have a regular reuse element- the UDDT system produces nitrogen-rich liquid fertiliser and organic soil conditioner; the biogas system produces biogas for cooking and organic soil conditioner; the wetland produces nutrient rich water for irrigation. The septic tank-infiltration system is mainly a disposal system; however, every few years it also produces a batch of organic soil conditioner.

While the UDDT does not require much space, it has to be constructed specially to achieve separation of waste streams within the toilet. The biogas requires sufficient space in a housing compound for underground construction and it is more likely to be successful if livestock manure is also added to the system. The constructed wetland is best demonstrated as a collective system with a group of households and needs enough land for construction, placed next to agricultural fields. The infiltration system also needs land for infiltration.

An activity plan has been drafted to implement alternative sanitation systems with the 42 target households. Important elements of the plan are: developing long-term support mechanisms which consist of institutional support and market service providers, exposure trips, and consultant expertise.

1.0 INTRODUCTION

1.1 Background

The source of most of the water supply for Herat city comprises ten deep wells from where groundwater is extracted at a depth of 85 m below the surface. These deep wells are situated at the southern outskirts of the city in the villages of Navin and Torkan, which are collectively referred to as the 'Navin Well-Field Area' for project purposes. The Navin Well-Field Area can be described as peri-urban; it was largely farmland, but in the recent years, it has been settled by returning refugees and many new houses have been built. This building-up around the deep wells is a potential threat to the water supply source since settlement activities can contaminate the water. Most significantly, the local sanitation system is a hazard because pollutants from the household latrines and soakage wells seep through the soil into the ground water.

The Department of Water Supply is currently in the process of negotiating with the community to purchase land within a 30 m radius of each well, which would be demarcated as a water protection zone where no agricultural or settlement activity would be allowed. However, this is not possible in some cases as roads, mosques, school or houses have already been built close to the wells. Therefore, as an additional measure to protect the wells, GTZ-Rodeco wants to work with the community to improve their existing sanitation systems such that they do not threaten the groundwater quality.

The immediate aim of the project is to upgrade the sanitation systems of the 42 households that lie within 70 m of the wells, and in doing so, test and demonstrate sanitation options which can then be replicated for the rest of the Well-Field Area and for other peri-urban areas with similar conditions. Therefore, from Nov. 23rd to Dec. 3rd, 2009 an assessment was carried out in the Navin Well-Field Area to determine suitable options for sanitation, and these options were then presented and discussed with the community in a workshop session. This report presents the findings of the sanitation assessment and the feedback session with the community and proposes the next steps for implementation.

1.2 Goal and Objectives of Project Interventions in Sanitation

The goal of the GTZ-Rodeco project interventions in sanitation in the Navin Well-Field Area is to protect the water supply source of Herat city from contamination.

The specific objectives of the project are to:

- introduce and implement sustainable, improved sanitation systems for the 42 households within the direct vicinity (within 70 m) of the deep water wells.
- test and demonstrate sanitation options which can be replicated in the rest of the Navin Well-Field Area and other peri-urban areas with similar conditions.

1.3 Situation in the Navin Well-Field Project Area

Information on the situation in the Navin Well-Field Area was gathered through a household survey conducted by GTZ-Rodeco; from on-site observations; and through meetings with village elders, men and women shura (council) representatives and other villagers. Navin and Torkan villages together comprise 574 households with a total population of approximately 4,500. In addition, there are 10 mosques, 1 school, and 1 communal bath in the area. Looking at the target area close to the deep water wells, there are 42 households with 386 inhabitants, the school is located next to Well No. 8 and has 2,000 students, and two mosques are also found near the wells.

The landscape of the Navin Well-Field Area is flat. The underlying soil type is mostly gravel with interspersed clay lenses[1]; the gravel gives the soil a high hydraulic conductivity and hence a higher risk of ground water pollution. The groundwater table in the area is high, ranging from 5.8 m to about 8 m below the surface. The annual temperature range is -5 to 38 °C; however, in extreme winters temperatures can fall down to -10 to -15°C. Precipitation is mostly during the winter and summers are hot and dry.

The infrastructure of Herat city and surrounding neighbourhoods is well developed compared to other major centres in Afghanistan. The project area is connected to the city's power supply which is currently a secure source from neighbouring countries, and hence the households have electricity most of the time. The well-field project communities are not yet connected to the city water supply (i.e. from the deep wells in their locality), but it is expected that they will be linked to the municipal network in the coming months with the completion of the local NSP[2] water supply project. Meanwhile, most households have a shallow well in their own yards at a depth of about 10 m. Some of the households take water from the few public wells (25 m deep) and the very poor are even reported to use water from the irrigation channels.

There is no wastewater canalisation and all households have individual toilet systems; for bathing, families typically go to the local community bath if possible or use a make-shift bathing area at home. While the quantity of water from the private shallow wells is sufficient for household needs, the wells have hygienically poor water quality because of contamination from the latrines, which cannot be placed at a distance of 15 m from the water wells owing to the shortage of spaces. The women reported that children suffered from diarrhoea and stomach aches because of the poor water quality of the shallow water wells.

During the summer, families with fields nearby may also use water from the shallow wells for irrigating the crops. In this case, the wells are dug a bit deeper at the time in order to extract more water. The irrigation period extends from early April to end of September. There are also irrigation channels running through the two villages, which divert water from the river upstream and then re-connect to the river downstream.

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[1] Personal communication with D. Guett; information is based on a geological assessment of the Navin Well Field Area.

[2] NSP is the National Solidarity Programme in which communities identify and implement a development project in their village with funds from the government and community contribution.

Energy for heating and cooking is taken from biomass and fossil fuels. Animal manure is collected, dried and burnt for cooking. People with surplus manure sell the manure as fuel. Alternatively, gas is purchased in cylinders and used for cooking. Coal and wood are used for heating.

Pic. 1: Irrigation channel outside the housing compounds (Source: N. Khawaja, 2009).

The well-field project area has different types of housing complexes and a mixture of socio-economic classes. Most families live in traditional compounds with residential rooms made in the local, mud construction style and have some yard space with trees and vegetables. The average compound size is 110 m² but some compounds are larger with spacious yard areas. Families may also have animals such as cows, goats, poultry and a donkey and have a section for the animals that may include a winter enclosure and an open summer area.

Pic. 2: A traditional compound with spacious yard area. The shallow water well is in the forefront and the toilet is located behind the greenhouse (source: N. Khawaja, 2009).

Pic. 3: View of traditional compounds and yard area for animals (source: N. Khawaja).

The plots with new constructions are smaller and have typical city-type brick and concrete houses and the surrounding yard area is small and completely paved with concrete. There are also a few very poor families who have inhabited abandoned mud-based buildings that are in disrepair.

Farming fields are interspersed through the villages and this land belongs to families living in the two villages as well as families who now live in the city; around 40% of the families in the well-field project area have their own fields in the vicinity.

Pic. 4: A newly constructed concrete house. The corner of the shallow water well is visible in the forefront and the toilet is the white room at the outer wall (source: N. Khawaja).

The household sanitation systems in the area are basically of two types – a 'simple latrine' or a pour-flush toilet connected to a sewage well. In a few extreme cases, the households have no excreta containment system and the toilet waste goes directly into the channel outside. The toilets for all of the systems are used in squatting positions with loam, water or toilet paper as anal cleansing material.

Most homes in the two villages have the so-called 'simple latrine', which is an above-ground raised vault that has a height of 1 - 3 m. The upper level of the vault is the floor of the toilet and has a hole for defecation. The bottom base is open ground and liquid gathered in the vault can flow into the soil and ground water. These containment units have an opening on one side of the vault and are usually emptied out manually at an interval of 1 - 6 months depending on the latrine depth and family size. Some households empty it out as often as once a week, and a few families use the services of a tanker to remove the excreta material. These latrines attract a lot of flies, are malodorous and are also visually unappealing for the user. The two mosques next to the deep water wells also have these 'simple latrines'.

Pic. 5: A pour-flush toilet of a newly constructed house (source: N. Khawaja).

The other sanitation system is a pour-flush toilet connected to an underground, off-set sewage well. While a small percentage of households from the complete Navin Well-Field Project Area have this system, from the target households close to the deep water wells, the majority of households, especially the newly constructed houses, are using this model (29 out of 42). The sewage well has an open base and the walls are assembled using 40 cm wide concrete rings. Some of the new houses have not constructed sewage wells with concrete walls but with only one concrete ring at the mouth of the well. These underground wells are between 3 - 8 m deep and are emptied out at intervals of 2 months to 3 years, usually by a tanker service but a few households empty it out manually. In some places a tanker is not able to have access to the sewage well.

The excreta emptied out from the latrines and sewage wells are considered useful for the land. The waste excreta that is removed manually is mixed with soil and either applied directly on to trees or fodder crops within the household compound or taken out to the fields, dried in the open for a few months, and then spread on to land cultivated with cereal crops. Women noted that in the summer season there are a lot of flies around the trees after the excreta have been applied. Families who do not have yards or their own fields request neighbouring farmers to accept the excreta on their lands. Tanker services that empty out the waste also dispose of the excreta on farmland. People reported that the process of emptying out of the above- and under- ground chambers generates a lot of smell.

The men and women have distinct roles related to sanitation. The task of manually emptying out the excreta from the sanitation units or arranging for its removal belongs to the male members of the family, while the women are responsible for the upkeep of the toilet.

The greywater production is currently low, at about 25 - 30 l generated per person in a day. However, with a connection to a direct water supply network, this is likely to increase; the Department of Urban Development uses an estimate of 40 - 50 l per person for connected households. The greywater is fed to plants and trees in the yard, guided to an irrigation channel outside the housing compound if available, or simply discharged outside the home boundary wall into the street. While the greywater is relatively much less problematic than the toilet waste, it forms stagnant pools or flows in rivulets if discharged into the streets. Moreover, the women reported that the greywater smells and they do not like using it on the plants because the plants become dry; they do it because they do not have any other option.

A discussion on hygiene aspects of sanitation revealed that while people were aware of the link between hygiene and health, only about 10% of the village practised hand washing with soap. Another sanitation related topic which surfaced as a matter of concern to the community was garbage. Households with animals fed most of their kitchen organic waste to the animals. However, ash residue from the cooking area, remaining organic matter and plastics were a nuisance; these were mostly swept out and dumped into open fields and they also accumulated in the rivulets formed by the greywater.

There is one school in the project area and it is located close to one of the deep wells (Well No. 8). It has noticeably inadequate sanitation facilities. The body of 2,000 students along with the teachers is served by one linear toilet block consisting of five toilets. There are no separate facilities for girls and boys or for teachers and students. The toilets are of the same form as the household 'simple latrines' described earlier and the collection vaults had a height of about 1 m. There is no water connection and the students have to use tissue paper for cleansing. There is an opening at the back of each vault for removing the excreta; the cover slab for the opening is kept open. The excreta is removed regularly by a farmer and reused on his fields. The toilets are unsightly, the excreta are open to flies, and the smell from the toilet block is apparent several metres away.



Pic. 6 - 8: The toilet block of the school with 'simple latrines' and opening at the back of the rasied vault to remove the excreta (source: N. Khawaja).

1.4 Preliminary Community Discussions

Preliminary discussions were held with the community to be able to gauge the existing situation in the Navin Well-Field Area, which has been described in Section 1.3. In addition, these discussions helped in understanding the perceptions of the community and their initial reactions to alternative sanitation systems. The GTZ-Rodeco engineering team met with the men's shura (council) and I had meetings with women from the shura, the target households and from the wider well-field area.

The communities were well aware that the cause of pollution of the shallow water wells in their homes was their existing toilet systems. They were hence also able to understand the risk of contamination to the deep water wells in their neighbourhood from the sanitation systems. Moreover, the households with the 'simple latrines' particularly complained of the associated smell and flies. The households with the underground sewage wells generally had a higher economic burden because they had to pay a tanker service, on average 600 - 700 Afghani ($12 - $14), for emptying out a well; they also had to deal with the nuisance of smell during this operation. Hence, the people were receptive to improving their sanitation systems if they would be supported in doing so.

The alternative sanitation system introduced to the men and women in the preliminary discussions was a model similar to their existing 'simple latrine' that solved the issues of ground water pollution, smell and flies while retaining the benefits of fertiliser for plants and crops. This was the urine-diverting dehydration toilet (UDDT), also commonly referred to as an ecosan toilet (see Section 2.1). The GTZ-Rodeco team gave an introductory presentation to the men's shura about this toilet. The men had no interest in this system and, given their existing unpleasant task of emptying out dangerous and smelly excreta chambers, they understandably did not want to engage in handling any form of excreta (even treated). The men rather preferred a system similar to their existing sewage wells- a water-proof, completely sealed sewage holding tank that would not leak- even if they had to pay for a tanker service to empty this system.

The interaction with the women was done in the form of discussions to build on their own reasoning. They were highly aware of the issues and wanted to take action. The women also suggested that the way of protecting the ground water and reducing the health hazard of exposure to excreta as well as smell and flies was to have a completely sealed underground sewage storage tank, which would be pumped out by a tanker and therefore not have to be handled manually.

They were also well aware that while exposure to fresh excreta was dangerous for health, it nevertheless was beneficial for the soil and cultivation of crops. Therefore, building on this aspect, they were then asked whether they would prefer to benefit from the nutrients of the excreta rather than getting rid of it, but without being exposed to smell, flies or health risks. The UDDT was briefly described. The women responded very positively to such a system even if it required manual maintenance and handling of some form of excreta. They felt that they could convince the men of their family to participate in operating such a system albeit the men's resistance to handling excreta.

1.5 Criteria for Selecting Alternative Sanitation Systems

A sanitation system comprises the complete flow chain of sanitation, i.e. from collection and storage to transport, treatment, and reuse or disposal. The Sustainable Sanitation Alliance[3] has identified five broad criteria that should be addressed to make a system effective and sustainable. These are: health and hygiene, environment and natural resources, technology and operation, financial and economic issues, and socio-cultural and institutional aspects.

Within the context of the Navin Well-Field Project Area, specific criteria that should be met by a sanitation system are as follows:

- the ground water is protected from contamination;
- health hazards are eliminated from the toilet and from any handling, treatment, transport, and reuse or disposal of excreta;
- the toilet systems are at an individual household level or small-scale decentral-ised (collective) level;
- the toilet system is user friendly (i.e. odourless and no flies);
- the operation and maintenance requirements are within the technical and economic capacity of the users[4];
- local materials are used and local habits are incorporated to make sanitation socially, economically and practically feasible;
- reuse aspects of sanitation (energy, fertiliser, water) are examined since they would be beneficial for the community;
- hygiene is integrated with sanitation (i.e. incorporate hand washing as an essential component of visiting the toilet).

[3] The Sustainable Sanitation Alliance (SuSanA) is an open network on sustainable sanitation (www.susana.org).

[4] The project has a budget for installing the sanitation systems and hence construction costs are not highlighted here though they are also a part of the financial and economic sustainability indicator.

2.0 OPTIONS FOR ALTERNATIVE SANITATION SYSTEMS

Four sanitation systems were selected based on the criteria given in Section 1.5. These are as follows:

1) Double vault urine-diverting dehydration toilet system (UDDT)
2) Fixed-dome biogas sanitation system
3) Constructed wetland wastewater treatment system
4) Septic tank with off-site subsurface infiltration wastewater treatment system

The first two systems treat only the toilet waste whereas the latter two treat the combined wastewater of a household (i.e. including the greywater). Separate treatment of greywater is not addressed in this report.

The systems were also selected keeping in view the various types of housing complexes. The UDDT would generally serve well in the traditional housing compounds because they have sufficient space for this type of toilet and for handling of the end products. The biogas would be suitable for the households that have cows and have spacious yards where the biogas digester can be constructed underground and the digestate can be handled.

The new concrete houses with their pour-flush toilets would be best connected via a local sewer to an externally constructed wetland system. Alternatively, the sewage wells of these houses could be replaced by a septic tank which would be connected to an off-site subsurface infiltration system (or also a constructed wetland). The new houses also have more problems with greywater because it is directly discharged into the streets, and these two sanitation systems also treat the greywater.

The first three systems listed above have a regular reuse element- the UDDT system produces nitrogen-rich liquid fertiliser and organic soil conditioner; the biogas system produces biogas for cooking and organic soil conditioner; and the wetland produces nutrient-rich water for irrigation. The septic tank-infiltration system is on the other hand mainly a disposal system; however, every few years it also produces a batch of organic soil conditioner.

A note on health aspects: a sanitation unit alone cannot protect health; rather a multi-barrier approach has to be followed to have maximum reduction of risks to health. The pathogens in excreta that are a threat can be grouped into bacteria, viruses, parasitic protozoa and helminths. A multi-barrier approach means following precautionary measures to reduce the risk from these pathogens at several steps of the sanitation chain – i.e. at the user interface, collection and transport, treatment and reuse steps - and in various ways – e.g. by habits and behaviour (hygiene and wearing protective items), by reducing exposure (selecting an appropriate fertilising method), by crop selection and processing methods (avoiding crops grown close to the ground or eaten raw), by avoiding fertilised fields, etc. Importantly, following a multi-barrier approach allows greater flexibility in treatment and reuse of excreta and thus it is possible to benefit from excreta as a resource rather than disposing it as a waste.

2.1 Double Vault Urine-Diverting Dehydration Toilet System

2.1.1 System Components

The complete schematic, showing the inputs, the system parts and processes, the outputs, and the final products, of the double vault urine-diverting dehydration toilet (UDDT) system is shown in Figure 1. The incoming material streams are urine, faeces, body cleansing water[5] and dehydrating material and the final outputs are fertilising products which can be used in agricultural activities. This system does not treat greywater.

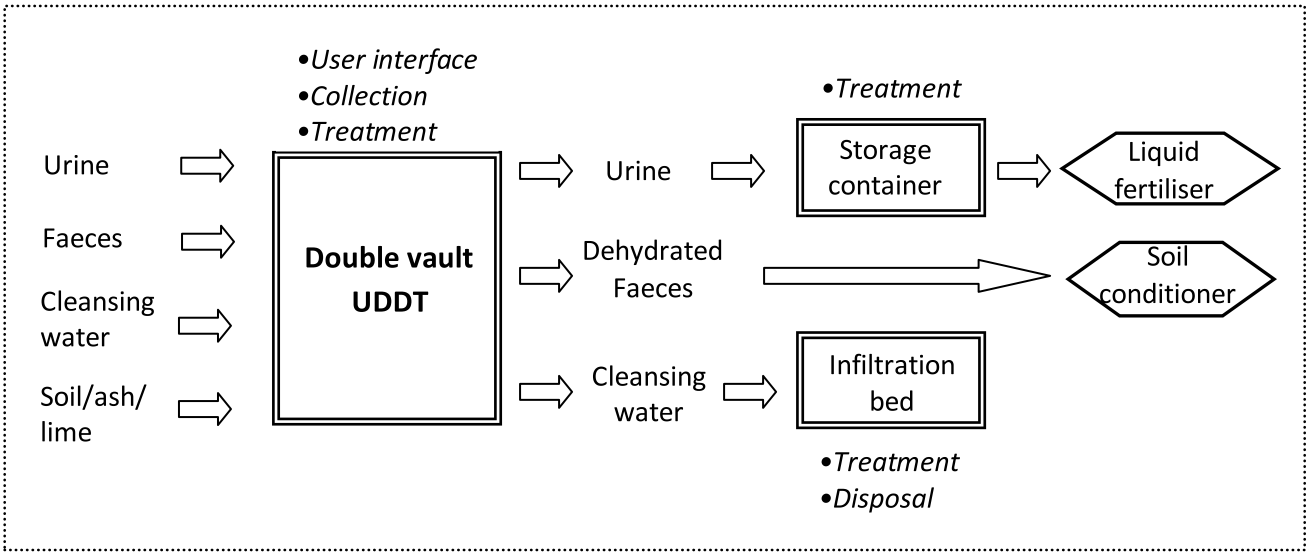

Figure 1: Schematic of the double vault urine-diverting dehydration toilet system.

2.1.2 Description[6]

A double-vault UDDT[7] is a system in which excreta waste streams are separated at source and collected, treated and reused or disposed separately. In a washer culture, three separate material streams are produced - faeces, urine, and cleansing water respectively, and in a non-washer culture, only the first two waste streams are produced. The toilet squatting pan has two or three outlets rather than the usual one outlet, one for each waste stream.

The UDDT consists of an above-ground substructure in which excreta are collected and a superstructure on top of that which houses the user interface. Faecal matter (and toilet paper or loam, if used) is deposited directly through the squatting pan or slab into a collection chamber below. Absorbents such as lime, ash, or dry soil are added to the

[5] If loam or tissue paper is used for cleansing, it is thrown into the faecal chamber.
[6] This section has been written based on information from Winblad and Simpson-Hebert (2004) and lecture notes of the 2008 Summer course on Sustainable sanitation- decentralised, natural and ecological wastewater treatment, at UMB, Norway.
[7] A single-vault UDDT was not chosen so that people do not have to handle relatively fresh faeces and to reduce the operational time requirements.

chamber after each defecation to absorb excess moisture, make the pile less compact and make it less unsightly for the next user. The addition of absorbents also reduces flies and bad odours. Moreover, depending on the additive, the pH may also be increased due to this addition, and hence enhance bacterial pathogen die-off. As breakdown of organic material in dehydrating conditions is slow, toilet paper or similar objects placed in the chamber will not disintegrate quickly. The hole in the squatting pan that is the opening to the faecal chamber is covered after use with a lid to reduce odour and flies.

The sub-structure is divided into two faecal collection chambers (i.e. double vault) and they are used alternatively. One chamber is used until it is full, after which it is closed and the chamber is put out of use, allowing the matter to dry out. The second chamber is then used. When it becomes full, it is closed and put into hibernation mode and the first chamber is emptied out and reused. This alternate use is done by having two squatting pans or designing two holes for faecal material in the floor of the superstructure. The collection chambers have doors at the sides to be able to remove the dried faecal material. A ventilation pipe leads out from the faecal chambers and extends above the highest point of the roof of the superstructure. This helps to dry the material and reduces smell in the toilet.

Pic. 9: A double vault UDDT in a school in Hayanist, Armenia showing one squatting pan out of use and covered with a lid and a bucket of sawdust and one squatting pan in use (source: Deegener et al., 2009).

Urine flows through the urine outlet in the squatting pan and via a pipe underneath into a urine collection container placed within or outside the substructure. Two small containers, with a small inlet for inserting urine pipe, are used alternately to collect the urine (note that for large families a larger collection tank may be needed). The urine containers have to be closed at all times to prevent odour and loss of ammonia into the air. Cleansing water is directed via a pipe underneath into an infiltration bed outside the UDDT. Each of the three collected waste streams is treated and reused or disposed, which completes the sanitation flow chain.

Pic. 10 - 11: A double vault UDDT in India (*Left*, source: ESF India) and in Sinalac School, Philippines. (*Right*, source: Sayre & Muench, 2009)

A sensitive issue for women may be that they do not feel comfortable using the UDDT during menstruation. A WECF Factsheet (WECF, 2009) explains the following. During a woman's menstrual cycle, blood will inevitably enter the urine and faeces chambers when she is using the toilet. However, this organic material poses no threat to the treatment process in either the urine or faeces chamber or to its future use as an agricultural fertiliser. The problem is purely an aesthetic one, which can be solved by cleaning the pan after use.

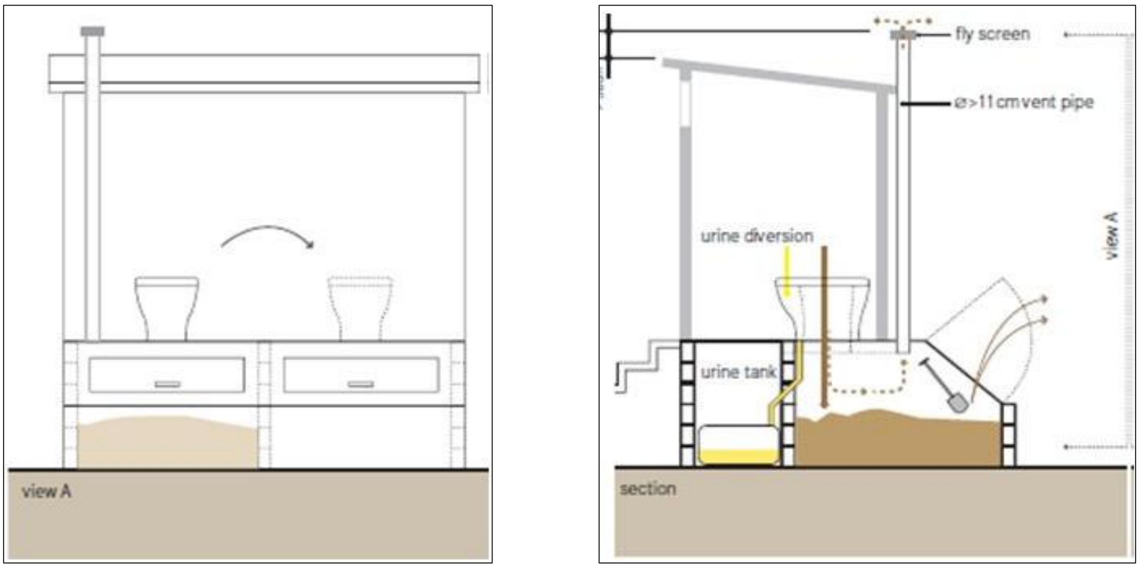

Figure 2 - 3: A schematic of two side views of a double vault UDDT showing the two faecal collection chambers and separate urine collection (source: Tilley et al., 2008). (Diversion of anal cleansing water is not shown here).

The waste streams are separated at source for several reasons. **Firstly**, faeces are the most dangerous component of excreta; they include almost all the pathogens and are the main source of disease transmission. In contrast, urine from a healthy person is sterile. Even for a sick person, the pathogens in urine are very few as compared with faeces and very few diseases are transmitted through urine. Therefore, keeping these streams separate means the aspect of hygienisation of urine becomes much simpler.

Secondly, urine has a high content of nitrogen in the form of urea, which naturally decomposes to the end product of ammonia. Ammonia is a volatile gas and escapes to the air from the liquid phase very easily, leading to a loss of valuable nitrogen from the urine. Ammonia also smells. Thus if urine is allowed to remain in the open air, the ammonia formed quickly escapes into the atmosphere, causing an unappealing odour. Moreover, the breakdown process of urea into ammonia is accelerated if faecal matter is mixed into the urine (again, causing stench and loss of nitrogen). A separated urine stream can be easily diverted to a sealed container where the nitrogen loss in the form of ammonia is low and odour is minimised.

Thirdly, if water is added to faecal matter, it creates anaerobic conditions (i.e. no oxygen) and the faeces cannot decompose as easily and quickly in anaerobic conditions as in aerobic conditions (i.e. with oxygen). Pathogens also survive better in wet environments. Moreover, anaerobic degradation generates odours whereas aerobic degradation is odourless. Similarly, if water is added to the urine stream, the diluted urine is not as effectively treated. Also, it is best not to mix anal washwater with urine to keep pathogen levels in the urine at a minimum, if urine is to be used as a fertiliser.

Lastly, if the faecal, urine and water streams are kept separate, their end-use can be more targeted and efficient. Urine is a liquid fertiliser with a high content of nitrogen and significant amounts of phosphorus and potassium, and faecal matter is a good soil conditioner and contains phosphorus and potassium.

2.1.3 Treatment Processes

Having the three separate material streams, the aim is to firstly minimise dangers of disease transmission and secondly to make them into a usable product. Several factors play a role in reducing pathogens in excreta. As explained in Section 2.1.2, the process of separating the faeces and the urine is already the first step in treatment because the faeces contains most of the pathogens while urine is usually sterile; only a few disease organisms are passed through urine. Treatment of pure urine is also necessary however, because of possible cross-contamination from faecal matter while using the toilet.

Faeces

In the double-vault toilet construction, at any point in time, one vault is used as the faecal chamber in service and the second vault serves as the treatment chamber. The vaults confine the faecal matter so that it is separated from the environment and human and animal contact while it is an active source of pathogens and while it looks unsightly.

Factors that kill pathogens in faeces include temperature, ultra-violet radiation, moisture reduction, alkalinity, and just time itself. Within the faecal chambers, the last three factors play the main role- the moisture content is reduced to about 25% or less, the alkalinity is increased if lime or ash are used as the dehydrating and cover materials, and the vaults are designed to hold the faeces for a sufficient length of time to kill off most of the pathogens.

The treatment design parameter that is used for faeces in a UDDT is storage time. According to the World Health Organisation's guidelines for the safe reuse of excreta, in warm environments (20°C - 35°C) storage times of less than one year, and in ambient temperatures (2°C - 20°C) storage times of 1.5 - 2 years, will be sufficient to eliminate most bacterial pathogens and substantially reduce viruses, protozoa and parasites. Some soil-borne ova (e.g. *Ascaris lumbricoides*) may persist (Muench, 2009a).

In the Navin Well-Field Area, considering that the temperature ranges from -5 to 38°C, one year should be sufficient as the storage treatment design time for a faecal vault. The high temperatures in the dry summers would compensate for the cold winters. Additionally, if ash from the kitchen stove or lime is used as the dehydrating material, the pathogen reduction will be enhanced.

Urine
The aim of urine management in the UDDT is to collect the urine in a sealed container in order to minimise nitrogen loss (via ammonia volatilisation) and to prevent odours in the toilet. The treatment of urine to make it safe for use as a liquid fertiliser is done separately off-site.

The factors that kill pathogens in urine are alkalinity from the rapid conversion of urea to ammonia, increased ammonia concentration together with the increase in pH, and time.

As with faeces, the design parameter used for treatment of urine is storage time. The WHO guidelines adopted for reuse of urine in agriculture recommend a storage time of 1 - 6 months, depending on the temperature and type of crop to be fertilised (Schönning & Stenström, 2004) (see Table 1).

Table 1: Recommended guidelines for storage time for urine mixture (urine that may be mixed with water) (Schönning & Stenström, 2004).

Storage temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4°C	> 1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	> 6 months	Viruses	Food crops that are to be processed, fodder crops
20°C	> 1 month	Viruses	Food crops that are to be processed, fodder crops
20°C	> 6 month	Probably none	All crops

In light of these guidelines, one month storage time for the summer and 3 - 6 months storage time for the winter can be recommended for the Navin Well-Field Project Area. Multiple larger storage containers, which can be sealed tightly, and an adequate storage space are needed for storing the urine. The count-down for the time of storage starts after the last filling with fresh urine from the smaller collection containers.

Cleansing water
Cleansing water is the water used for anal cleansing[8]. It is low in nutrients but has faecal matter in it and must not be released untreated into the environment. The simplest method for the small volumes of wash water produced in a toilet is an evapo-transpiration bed filled with medium sized sand and soil. If the bed is sowed with plants, then the transpiration of the plants as well as direct evaporation to the atmosphere, are the treatment mechanisms for the wash water. Alternatively, in places

[8] Hand washing water can also be added to this stream for treatment because it is a small amount of water.

where the local soil has good infiltration capacity, there can be the possibility of releasing the water into an infiltration trench.

2.1.4 Product Handling

The UDDT system produces two products- dehydrated faeces and urine- which have to be handled as a part of the system. Since they contain many of the nutrients which have been consumed through food, their reuse in agriculture closes the nutrient cycle in nature and helps to reduce the need for mineral fertilisers. The benefits of treated urine and faeces as a fertiliser and its application methods have been well documented in SuSanA (2008), PuVeP (2008), Morgan (2007), WHO (2006), Jönsson et al. (2004) and EcoSanRes (2008). Some of the main points are presented below.

It is important to note that in line with the multi-barrier approach, good personal hygienic practices should be followed when using these products, such as, wearing protective boots and gloves and washing hands after handling the products. Moreover, application of both treated urine and faeces must be stopped one month before harvest time to minimise exposure. A final protection barrier is to not eat the crops raw.

The product from the faeces dehydration process, a crumbly, powdery material, is not compost but rather a kind of powder which is rich in carbon and fibrous material, phosphorus and potassium. This is used as a soil conditioner which increases the organic matter of the soil, and hence improves soil structure and water-holding capacity, and acts as a slow release fertiliser (Muench, 2009a). The optimum time of application is prior to planting or sowing because the high phosphorus content is beneficial for root formation of young plants.

Pic. 12: Dried faeces after several months of storage (source: PUVeP, 2008).

The faeces should be thoroughly mixed in and covered by soil before cultivation starts, and it should not be the only growth medium. The application rate can be done on a phosphorus equivalence to P-based fertilisers or on the need for organic matter by the soil. The application rate based on phosphorus content is usually much lower than for organic matter enrichment (EcoSanRes, 2008).

Urine is a quick acting, nitrogen-rich fertiliser which also contains the macro-nutrients P, K and S (phosphorus, potassium and sulphur[9]) as well as sodium and chloride. The fertilising effects of these nutrients in urine are the same as those of artificial mineral fertiliser if the same amount of N, P and K is applied. The composition of urine makes it well suited as a fertiliser for crops thriving on nitrogen (such as maize) and especially

[9] Sulphur is an important macro-nutrient, needed in approximately the same amount as phosphorus, and often lacking.

for crops also enjoying sodium, such as chard (similar to spinach). Care should be taken when applying it for crops sensitive to chloride (e.g. potatoes and tomatoes), although yields of these crops can also be much improved by appropriate urine application.

Pic. 13: Stored urine available for re-use (source: PUVeP, 2008).

Specific application rates of urine depend on the crop, the soil type, and the climate. In order to avoid leaching and for climates with heavy rainfall or very sandy soils, frequent application of small amounts of urine is favourable but not essential. However, in general, it can be said that if all the urine from one person is collected, it will suffice to fertilise about 300 - 400 m^2 of crop area per person per year, producing for example 250 kg of maize (and this amount is roughly equal to the calorific food intake of one person per year). The crop yield though also depends very much on the soil, and urine will always work better in "living soils" compared to barren, sandy soils. As stated above, soil quality can be improved by incorporating the dried faeces into the soil. Further, nitrogen converting bacteria must be present in the soil (EcoSanRes, 2008).

Guidelines on the most effective methods for urine application are also given in the literature. The urine can be applied in the pure undiluted form followed by irrigation with water or first diluted with water and applied as a mixture to the soil. While undiluted urine is less in volume, diluting the urine reduces odour during application.

In the case of Navin Well-Field Area, it is critical to note that urine must not be dumped collectively on to the soil. While infiltration of urine directly into the soil via a soakaway pit and possibly using the soaked soil for agriculture is one way of handling urine, it leads to nitrates leaching through the soil and into the groundwater, which would defeat the purpose of protecting the deep water supply wells.

Pic. 14: Reuse of urine in gardening (source: GTZ).

2.1.5 Operation and Maintenance

An important condition for the success of UDDTs is that sufficient user commitment to the operation and maintenance can be provided.

Operation

The main operational requirement when using UDDTs is that the faeces vault is kept as dry as possible (no addition of urine or water). The purpose of adding covering material is to reduce odour, assist in drying of the faeces (soak up excess moisture), prevent access for flies to the faeces, improve aesthetics of the faeces pile (for the next user), and increase pH value (achieved when lime or ash is used). The toilets must always have the materials needed for use available within the toilet. Most importantly, this includes the dehydration material needed to cover the faeces after each use and a tight lid that covers each defecation hole in the squatting pan or slab.

The following points must be followed when using the toilet:

- Each part of the toilet pan should be strictly used for its respective purpose.
- Faeces must not enter the urine collection basin. In case this occurs, the urine container should be disconnected and removed. The urine in it should either be disposed off safely or stored separately for one year before use.
- Urine should not be directed at the faeces hole in the squatting pan. If a lot of urine enters the faeces hole, additional covering material should be used to absorb the urine and prevent smell.
- Water should not be poured into the urine basin. If water enters, the urine will be diluted and should be stored for longer to hygienise it.
- Users should know which faecal vault is currently in use. The storage vault should be temporarily sealed.
- After each defecation, two bowls or shovelfuls (200 - 500 ml) of dry absorbents should be sprinkled over the faeces.
- After each faecal deposit, the lid should be replaced on the hole.

Maintenance

The following points of maintenance should be followed:

- Before the first use, the vault floor should be covered with a 3 cm thick layer of dry powdered earth to absorb moisture from the faeces and to prevent faeces from sticking to the floor.
- A bucket of water with a brush or cloth should be available in the toilet for cleaning the pan at regular intervals, especially removing traces of faeces or menstrual blood, without pouring water in the excreta collection holes.
- At the time when the urine collection container is full, the urine collection pipes should be cleaned. This can be done by placing a bucket at the end of the collection pipe and pouring some water and acetic acid down the pipe to clean out the deposits.
- The first vault should be used till it is full, following which the vault lid should be temporarily sealed so that it is not used again until it is emptied out.
- The ventilation pipe should be dismantled and cleaned when needed. Cobwebs especially hinder the flow of air.

- Protective gloves should be worn when cleaning the toilet and the chambers. Hands must be washed after handling the urine container, cleaning the squatting pan, and emptying out the faecal chambers.

2.1.6 Design Information

The UDDT should be built entirely above ground to allow easy access to the faecal collection chambers. The chambers should be placed on a solid floor of concrete, bricks or clay, elevated around 10 cm above ground level, so as to avoid flooding in rain. The faecal chambers have to be individually accessible through access hatches or doors.

The toilet floor can be made from a moulded concrete slab or inserted with pre-fabricated elements made from plastics, porcelain or concrete, with separate outlets for urine, faeces and anal cleansing water. If a concrete slab or pan is used, it should be painted with a waterproof, resistant floor paint to ensure hygienic conditions and for ease of maintenance (proper cleaning and minimising the risk of bacteria surviving on a rough surface).

Pic. 15: A 3-hole urine-diverting ceramic squatting pan (source: GTZ Germany)

Links to suppliers of three-hole squatting pans and to a local organisation (VWO) that makes moulded concrete urine-diverting slabs near Herat city are given in Section 2.1.8. For this demonstration phase in the Navin Well-Field Project Area, it is recommended to use ceramic pre-fabricated three-hole squatting pans because they give the appearance of a high status toilet and hence people may be more willing to use it and maintain it. Such pans can be purchased from India. The VWO urine-diverting concrete slabs are locally available; however, if they are to be used, it should be checked whether anal cleansing with water is possible with the design of the slab.

The superstructure can be built from any material, depending on the users' preferences and local availability (Muench, 2009a).

Important for the function and comfort of a UDDT is the ventilation system. This consists basically of a pipe that leads from the collection chamber to the outside and ends well above the toilet roof. The wind can then draw moist air and odours from the chamber through the pipe. The pipe outlet should be sealed with a mesh to trap flies. The ventilation effect can be enhanced by using a T-shaped attachment at the top of the pipe or by a wind-propelled or electric fan (Muench, 2009a).

The design parameters to estimate the volume needed for storing the faeces and urine, using an example of 10 adult users, are shown in Table 2. It can be seen that one faecal chamber needs about 0.9 m^3 of space for storing faeces for one year. The chamber itself would be made slightly larger so that the material does not fill up right to the top.


Pic. 16 - 17: *Left.* A 20 l plastic jerrycan for urine collection (source: E. v. Muench, 2006). *Right.* A below-ground plastic urine storage tank (source: Kvarnström et al., 2006).

The volume needed for storing urine off-site for treatment of 1 month, 3 months and 6 months are 0.36 m^3, 1.08 m^3 and 2.16 m^3 respectively. These amounts do not have to be in one container; they can be split into smaller units as per the convenience of the households. It should be noted that an average adult produces 1.2 l of urine per day. If the size of a family is large, the collection and storage of urine in the UDDT may have to be organised using an underground tank and pump (corrosion resistant) rather than a container.

Table 2: Design parameters for the faecal vaults and for urine storage off-site for ten adult users.

No. of users	Amount per person in a day[10]	Approx. Density	Percent volume reduction	Storage time	Storage volume required
Volume needed for storing faeces in one faecal chamber					
Faeces					
10	0.15 kg/d	1 kg/l	75%	1 year	0.137 m^3
Dehydrating material					
10	0.2 l/d			1 year	0.730 m^3
Total volume					0.867 m^3
Volume needed for urine storage					
10	1.2 l/d			1 month	0.36 m^3
10	1.2 l/d			3 months	1.08 m^3
10	1.2 l/d			6 months	2.16 m^3

The evapo-transpiration bed is a simple plant box next to the UDDT without any specific dimensions for a household toilet.

Pic. 18: An evapo-transpiration box at the side of the UDDT (source GTZ, Philippines).

[10] Average amount for an adult user

2.1.7 User Criteria

Keeping in view the specifications, the design, the product handling, and the operation and maintenance needed for the UDDT system, the following criteria should be met by households wanting to implement a UDDT:

- Space for the construction of a UDDT structure.
- Space for urine storage.
- Ability to manage urine regularly from collection to the storage area.
- Commitment to proper use and maintenance of the UDDT.
- Commitment to reuse of products for agriculture.
- Use of guidelines for excreta reuse in agriculture and application of hygienic practices.

2.1.8 Information Links for the Design and Construction of UDDTs

Suppliers of urine-diverting squatting pans and slabs

- A worldwide list of suppliers of parts for UDDTs has been compiled by GTZ, which includes suppliers of three-hole squatting pans.
  http://www.gtz.de/en/dokumente/en-urine-diversion-appendix-suppliers-lists-2009-14-May.pdf
- The organisation Voice of Women Organisation, Herat makes moulded urine-diverting concrete slabs for a UDDT toilet floor (see VWO information below).
  Address: Badmorghan, across from Masjidul Reza, Herat, Afghanistan
  Telephone: +93 (0) 22 60 61/ (0)799 209 386
  Email: vwo_afg@yahoo.com

Design and Construction Guidelines

- Information on urine piping and storage tanks have been compiled by Muench and Winker (2009).
  http://www.gtz.de/en/dokumente/gtz2009-en-technology-review-urine-diversion.pdf
- Information on how to construct a UDDT is given by Deegener et al. (2006)
  http://www.susana.org/images/documents/07-cap-dev/a-material-topic-wg/wg04/deegener-et-al-2006-urine-diverting-toilets-wecf-en.pdf

Technical drawings

- Several links to technical data sheets and drawings of double vault UDDTs are available through the SuSanA website.
  http://susana.org/lang-en/cap-dev/visual-aids-drawings/technical-drawings
- Selected construction plans of UDDTs are given from projects around the world.
  http://www.gtz.de/en/dokumente/en-ecosan-tds-02-c1-dehydration-toilets-plans-2006.pdf

Videos

- A video link on the construction of a double vault UDDT is available on the SuSanA website.
  http://susana.org/lang-en/videos/ecosan-udd-toilet-construction-video

- A video link showing the opening of the hibernating faecal chamber (to remove and use the dehydrated faeces) is available on the SuSanA website. http://susana.org/lang-en/videos/uddt-first-opening-of-the-collection-chamber

Voice of Women Organisation UDDTs, Herat

The Voice of Women Organisation (VWO) is an implementing partner of UNICEF for the Clean Village Project. One of their two target villages is Khowaja Surmaq Village in Injeel District outside of Herat City. A core activity of demonstrating a clean village is the establishment of 'eco-sanitary' toilets (VWO, 2009). VWO first trialled single vault UDDTs but are now constructing double vault UDDTs with households and the faecal chambers allow a storage time of approximately six months. In their experience, 30 – 40% of the families use the urine as fertiliser in their gardens and 85% of the households use the dried faeces as soil conditioner on the land. Reportedly there are no issues of smell and flies from the toilets and about 85% of the user are maintaining the toilets.

A women's committee in the village makes urine-diverting squatting slabs out of concrete which serve as the toilet floor of the UDDT. VWO supports the construction of the substructure (the faecal chambers) and the concrete slabs. The households have to make the superstructure (pers. comm. Najib Noori, GTZ-Rodeco, Dec. 2009).

Pic. 19 - 20: *Left.* Moulded concrete slab of a urine-diverting toilet made by the women's committee. *Right.* The substructure of a double vault UDDT in the Clean Village Project (source: VWO, 2009).

2.2 Fixed-Dome Biogas Sanitation System

2.2.1 System Components

The complete schematic, showing the inputs, the system parts and processes, the outputs, and the final products, of the fixed-dome biogas sanitation system is shown in Figure 5. The human excreta, cleansing water and flush water enter together into the pour-flush toilet, and along with animal manure and any kitchen organic waste, they are the input materials for the fixed-dome biogas digester. The final outputs are biogas to be used as cooking fuel and digestate to be used as soil conditioner for agricultural activities. In addition, inert materials that have accumulated in the biogas unit have to be removed periodically. This system does not treat greywater.

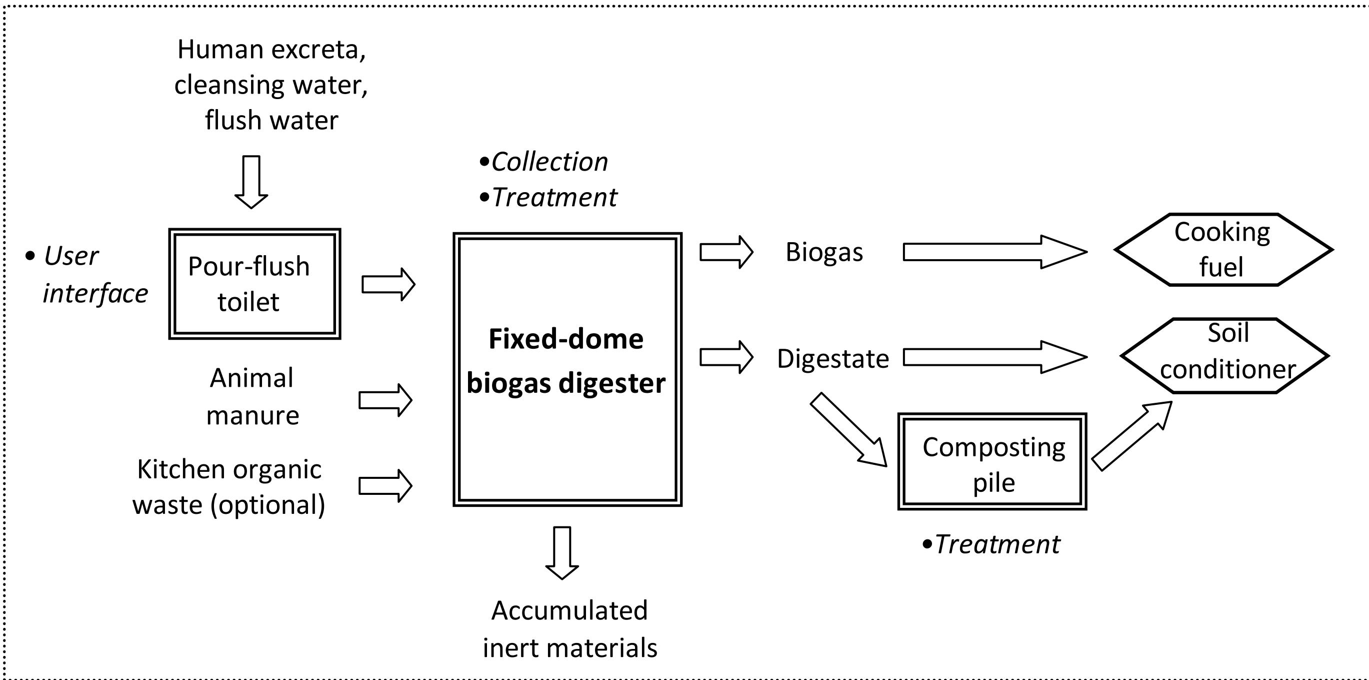

Figure 4: Schematic of the fixed-dome biogas sanitation system.

2.2.2 Description

In a fixed-dome biogas sanitation system, microorganisms break down the organic matter in excreta under anaerobic (without air) conditions, producing a methane-rich biogas and a digested organic matter slurry in the conversion process (Kossmann et al., 1999a). In this system, all toilet inputs can be combined, i.e. human excreta, cleansing water or toilet paper and toilet flushing water[11], and they are collected and treated in the 'biogas digester'. While the main aim of installing this system is to contain and treat toilet waste, the secondary aim is to provide biogas which can partially replace cooking energy needs of the household and thus be an incentive for the upkeep of the system.

[11] It is also possible to use a urine-diverting flush toilet and use the urine separately as a liquid fertiliser (Mang and Li, 2009).

Not all the organic matter (i.e. carbon based compounds) in the feed stream of the biogas unit is converted to biogas. For example, only 40 – 60 % of the organic matter in faeces is converted to biogas. The remaining organic matter comes out as a slurry called the digestate. Most of the nutrients (N, P, K) that are found in excreta are preserved during anaerobic digestion and are also found in the digestate. Therefore, the digestate is the other important product of the biogas sanitation system- the organic and nutrient content make it a valuable soil conditioner (Mang & Li, 2009).

The organic input stream must have a water content of at least 50% for the digestion process to take place (Muench, 2008). However, with too much dilution, the biogas production reduces significantly. Therefore, the proposed biogas system is attached to a pour-flush toilet and all water used in the toilet enters the digester, but greywater is excluded from the system to prevent over-dilution.

The biogas digester, as a single household sanitation system attached to toilets alone, produces little biogas. In comparison, as an approximation, one cow equals 17 people with respect to biogas production from excreta (Muench, 2008). Therefore, it is suggested that households must have at least one cow, preferably more, to implement such a system. Additionally, kitchen organic waste can also be added to the system if available.

Biogas, in general, comprises 50 - 75 vol.% methane, 25 - 50 vol.% carbon dioxide, and varying quantities of nitrogen, hydrogen sulphide, oxygen and ammonia. However, specifically, the proportion of methane in biogas varies with the input material- approximately 50, 70 and 84 vol.% for carbohydrates, fats and proteins respectively- and the higher the proportion of methane, the higher the calorific or fuel value of the biogas (Muench, 2008).

Anaerobic degradation is theoretically possible between 3°C and approximately 70°C. The rate of bacteriological methane production, however, increases with temperature[12], and furthermore, if the biomass temperature is below 15°C the biogas production is reportedly too low to be economically beneficial.

A biogas digester is operated at one of three temperature ranges: psychrophilic (< 20°C), mesophilic (20 – 40 °C), or thermophilic (> 40°C), and within the operating temperature setting, the digestion process is very sensitive to changes in temperature. For example, in a psychrophilic-operated reactor (which is typical for below-ground, household fixed-dome reactors), fluctuations have to be limited to ± 2°C/h (Kossmann et al., 1999a).

The microbiological activity in a digester and therefore the treatment processes and rate of biogas production are affected by many factors (Kossmann et al., 1999a; Mang, 2008; Muench, 2008; Balasubramaniyam et al., 2008). Temperature is the most important factor and its effect on the digestion process has been explained in the previous paragraphs. Another important factor is the retention time. The level of degradation of the organic matter (visible by the amount of gas produced per amount of organic matter) increases as the retention time rises until it reaches a point where very little

[12] Note: if the amount of free ammonia increases with temperature, the bio-digestive performance could be inhibited or even reduced as a result.

extra gas is produced with more time. Digesters operated at a lower temperature need a longer retention time to achieve similar gas production as at higher temperatures.

The type of input material into the reactor also affects the rate of biogas production. High volumes of biogas are produced in a short time with organic materials that are easy to degrade. These include sugars, vegetables, fats and faeces. In contrast, harder to degrade organic materials such as grass, leaves and wood chips, have a lower rate of biogas production. The harder to degrade materials have high carbon to nitrogen ratios. Nutrient availability in the input material also plays a role in degradation.

Other factors include pH level (see Sections 2.2.3 and 2.2.5), substrate solid content (see above), mixing to enhance inoculation effect amongst other objectives, and inhibitory factors such as ammonia and heavy metals. Further details on these factors can be found in (Kossmann et al., 1999a).

In engineering terms, the fixed-dome biogas digester resembles a completely stirred tank reactor (CSTR). Thus theoretically, it is a homogeneous system and the hydraulic (liquid) and sludge (solid) retention times are the same, and practically, these household biogas plants do not aim for solids settling but rather for good mixing[13]. Therefore the reactor outlet is from the bottom of the tank rather than from the top (as it is in a septic tank). The plants produce a continuous flow of digestate, and de-sludging of the digester is only necessary if there is a build-up of inert material such as sand (Muench, 2008).

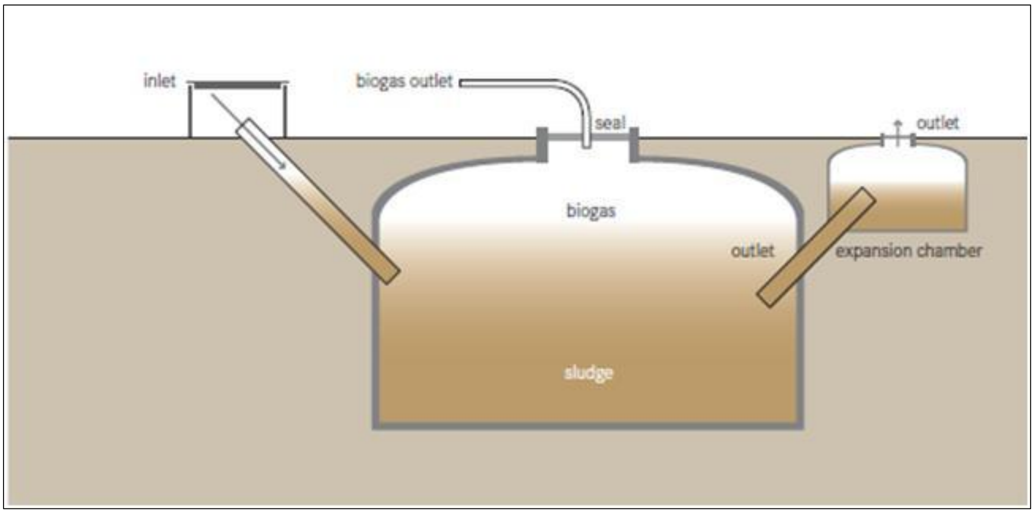

Figure 5: A schematic of a household, fixed-dome biogas digester. As gas is produced in the digester, slurry is pushed up into the expansion chamber at the right side. When the gas is consumed, the slurry flows back into the digester (source: Tilley et al., 2008).

[13] In China, some biogas digesters are made with an internal baffle wall to make the sludge retention time longer than the hydraulic retention time and hence give more time for pathogen die-off in the sludge (Mang, 2008).

Pic. 21 - 22: Construction of a fixed-dome biogas digester near Hanoi, Vietnam (source: GTZ).

The fixed-dome plant model is constructed below ground. It consists of a biogas digester base with a fixed, non-movable gas holder located on top of the digester. When gas production starts, the slurry is displaced into the expansion chamber. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the expansion chamber (Kossmann et al. 1999a). When gas is consumed, slurry enters back into the digester from the expansion chamber (see Figure 5). As a result of these movements, a certain degree of mixing is obtained of slurry of different ages (Balasubramaniyam et al., 2008). The advantages and disadvantages of the fixed-dome digester are given below (Kossmann et al., 1999a; Balasubramaniyam et al., 2008).

Advantages:

- relatively low construction costs;
- the absence of moving parts and rusting steel parts;
- if well constructed, fixed dome plants have a long life span, up to 20 years; and
- the underground construction saves space and protects the digester from temperature changes[14].

Disadvantages:

- high technical skills are required for a gas tight construction;
- special sealant is required for the gas holder;
- the gas pressure fluctuates substantially depending on the volume of the stored gas;
- the amount of gas available for cooking is hard to detect; and
- even though the underground construction buffers temperature extremes, digester temperatures are generally low.

[14] The temperature fluctuations between day and night are no great problem for plants built underground, since the temperature of the earth below a depth of one meter is practically constant.

2.2.3 Treatment Processes

Anaerobic digestion taking place in the fixed-dome biogas unit is the primary treatment process for the excreta (and manure) collected in the unit. The digestion is a multi-stages process (hydrolysis, acid formation stages- acidogenesis and acetogenesis, and methanogenesis) performed by different microorganisms. In biogas sanitation systems, the different degrading reactions take place in one digester.

The digestion process starts with hydrolysis of the input materials, through extracellular enzymes released by bacteria, in order to break down insoluble organic polymers such as carbohydrates into simpler substances. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Next, the acetogenic bacteria transform the resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. At the last stage of the process, methanogens convert these products into methane and carbon dioxide (Mang & Li, 2009).

The acid-producing bacteria and methanogenic microorganisms have an interdependent relationship and their metabolic actions together complete the digestion process. The acid producing bacteria consume oxygen and create the anaerobic atmosphere required by the methanogens. They also prepare the low molecular weight compounds needed for methanogenesis. The methanogens consume the intermediate products of the acid producing bacteria and prevent toxic conditions from developing (Kossmann et al., 1999a). Here it is important to note that if acids accumulate in the system, the fermentation process will stop and no more gas will be produced. This is called a 'sour' digester and is usually very smelly (Muench, 2008).

Methanogens are slow growing microorganisms. Therefore, the material in the biogas digester must have a minimum retention time in order to prevent the methanogens from washing out of the system (Mang, 2008).

The treatment result of anaerobic digestion can be summarised as follows. The organic matter is broken down into simpler molecules. There is a high level of organic matter removal, but some organic matter remains in the digestate. There is no removal of the nutrients nitrogen and phosphorus and there is no removal of heavy metals. The digestate also has reduced odour (Muench, 2008).

The inactivation of pathogens during the treatment process depends on temperature and retention time. Pathogens die easily in thermophilic conditions in any system (i.e. > 50°C for several days). In the lower-temperature psychrophilic operating conditions of a fixed-dome biogas reactor, retention time plays a critical role. Mang and Li (2009) report findings from Zhang Wudi in China that a retention time of 60 days in a psychrophilic biogas unit reduces pathogens significantly. As Table 3 shows, the main pathogens are largely killed off during this time period. Only Ascaris eggs remain persistent.

Table 3: Effects of anaerobic sanitisation on selected pathogens, parasitic ova and E. Coli indicator (Source: Zhang Wudi, BRTC, China 1985) (Mang & Li, 2009).

Pathogens & parasitic ova	Ambient temperature fermentation (8-25°C)	
	Days	Fatality (100%)
Salmonella	44	100
Shigella	30	100
E. Coli titre	40 - 60	$10^{-4} – 10^{-5}$
Schistosoma ova	7 – 22	100
Hookworm ova	30	90
Ascaris ova	100	53

The digestate can be treated further through an aerobic co-composting process with carbonaceous materials such as crop residues. This reduces the nitrogen losses from the liquid digestate and the thermophilic temperatures reached in properly carried out composting processes destroy pathogens and parasites that have survived the anaerobic digestion treatment. The digestate is beneficial for the composting of carbonaceous materials because it provides a source of nitrogen for accelerating the process and enriches the compost with nutrients (Kossmann et al., 1999b).

2.2.4 Product Handling

The biogas sanitation system generates two products in the treatment process - biogas and digestate – which have to be managed as a part of the system. These products contain the energy and nutrients of the system input materials and therefore have a high reuse value. Biogas is a fuel, and at the small-scale household level, the biogas produced can be used in gas stoves for cooking or in gas lamps for lighting. The digestate is an additive for agricultural soils.

The preliminary discussions with the community in the Navin Well-Field Area showed that there is a high need for cooking fuel. Currently, families use dried cow dung for cooking, which emits smoke into the surroundings and the women complained that even the tea tastes of smoke. This also means that the valuable nutrients in the cow dung cannot be used to fertilise the fields of farmers. Alternatively, households have to purchase expensive gas in cylinders for cooking.

As mentioned in Section 2.2.2, biogas has 50 - 75 vol.% methane (i.e. the fuel component). In comparison, natural gas has 97 vol.% methane (Muench, 2008); thus biogas has a lower calorific value than natural gas. Directly comparing the energy value of the two gases, 1m^3 of biogas is equal to 0.75 m^3 of natural gas (Mang, 2008). Comparing with the fuel value of cow dung, 1 kg dried cow dung corresponds to 100 l biogas (Kossmann et al., 1999a).

Although the rate of biogas production depends on a variety of factors[15], Bracken et al. (2009) report from literature an indicative value of biogas production - excreta from 50 - 90 humans or 2 - 3 cows in a day are needed to produce approx. 1 m^3/d of biogas, which is enough to cook three meals for a family of 5 - 6 members. It should be noted, however, that gas production generally drops in the winter even with the underground construction of the fixed-dome biogas unit (Balasubramaniyam et al., 2008).

To be able to use the biogas for cooking, specially designed biogas burners or modified consumer appliances are needed. Biogas needs less air for combustion as compared to other gases. Therefore, conventional gas appliances need larger gas jets when they are used for biogas combustion. The modification and adaptation of commercial-type burners is usually done experimentally. Fluctuating gas pressure in the fixed-dome biogas digester model can however complicate gas utilisation (Kossmann et al., 1999b).

Pic. 23: Biogas being used in a cooker in a girls high school (source: GTZ).

Household biogas plants produce a continuous flow of residue digestate which is a fertiliser and soil conditioner for agriculture. The macro-nutrients nitrogen, phosphorus and potassium in the excreta, manure and organic matter input material are preserved and mineralised during the anaerobic digestion process, making them easily available to plants. Some carbon compounds still remain in the digestate and therefore increase the soil organic matter content (Bracken, et al., 2009). This in turn enhances water holding capacity and soil aeration, accelerates root growth, and inhibits weed seed germination (MoA China, 2005).

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[15] (see Section 2.2.2) such as the type of substrate, the residence time of the input material in the digester, but most importantly, on the operating temperature.

The digestate can be applied to the soil as a liquid slurry or first dried before application. Kossmann et al. (1999b) give details about these procedures. To summarise, the nitrogen content of the digestate is preserved most if it is stored only briefly as a liquid slurry in a closed pit or tank and if it is dug into the soil to prevent losses during field application. Using liquid slurry thus requires storage tanks and a means of transporting the material. Drying the digestate reduces the volume and weight of the digestate and can make manual spreading easier; however, it results in high losses of the total nitrogen content (Kossmann et al., 1999b).

Pic. 24: Dried sludge from a biogas digester (source: GTZ).

Pathogen reduction of the slurry in the psychrophilic-operated household biogas reactors depends on the retention time. This is the first barrier for health safety. In line with the multi-barrier approach, other barriers should be observed when using the digestate such as wearing protective clothing, good personal hygienic practices and application guidelines (time and crop restrictions).

If the digestate is further composted with other organic matter, the resulting compost is also a soil conditioner and a source of nutrients. It is moist, compact and can be spread out by simple tools. With most available transport facilities in developing countries, it is easier to transport than liquid manure (Kossmann et al., 1999b).

2.2.5 Start-up, Operation and Maintenance

The fixed-dome household biogas plant requires careful attention to start-up, operation and maintenance for sustained use.

Start-up

A biogas digester requires time to achieve a stable digesting process. This is described in detail in Kossmann et al. (1999b), and some points are highlighted here. Depending on the input material, the start-up time can last from a few days to a few weeks. The initial filling of the digester is the innoculant for the biological process and this should be digested sludge from an existing operational biogas plant or cattle dung. The breaking-in period is characterised by:

- Low quality biogas containing more than 60% CO_2
- Very odorous biogas
- Sinking pH
- Erratic gas production

The first two gasholder fillings should be vented unused for reasons of safety, since residual oxygen poses an explosion hazard. Additionally, less-than-optimum performance of the gas appliances can be expected initially due to inferior gas quality.

Pic. 25 - 26: *Left.* Access hole to a biogas digester. *Right.* Flaring biogas (source: GTZ).

Operation

The important aspects of operating a biogas plant include the following (Balasubramaniyam et al., 2008; Kossmann et al., 1999b):

- Feeding fresh manure into the plant.
- Transporting the digestate to a storage facility or to the fields regularly.
- Checking gas pipes regularly for leaks.
- Checking and cleaning the overflow regularly.
- Checking the main plant health indicators (odour, foaming, no or low biogas production).

The main possible causes of a failing household biogas plant (detected by the health indicators) are an overload of organic matter and insufficient alkalinity and therefore a drop in the pH. The overloading issue can be remedied by reducing the feed into the reactor and the pH can be remedied by adding e.g. lime (Muench, 2008).

Maintenance

The main maintenance requirement of a fixed-dome biogas unit is cleaning out accumulated materials in the plant. During operation, some materials settle in the digester, such as sand or other heavy non-digestable materials, which decrease the effective digester volume and lead to a reduction in gas production. The complete digester has to be emptied out to remove these materials.

Balasubramaniyam et al. (2008) state that literature recommends a cleaning out rate of once every five years for fixed dome digesters. On the other hand, Muench (2008) mentions that the expectation for desludging a household biogas plant should be greater than 15 years. (Kossmann et al., 1999b) also mention annual maintenance activities. These consist of removing swimming layers in the plant and exposing the whole plant to a pressure test once a year to detect lesser leakages.

2.2.6 Design Information

The most important design parameter for the fixed-dome biogas digester is the retention time, which is the length of time the liquid stays in the reactor (Muench, 2008). The retention time depends on the process temperature and the type and concentration of the input material (Mang and Li, 2009). Once the retention time for the process has been established, the effective volume required for the digestion part of the reactor is give by the following equation (Muench, 2008):

$V = Q \times RT$

Where:
V volume (m^3)
Q flow rate (m^3/d)
RT design retention time

Digesters are designed for an optimum economic balance between gas yield and volume requirements, while keeping in view hygienisation aspects (see Section 2.2.3). Optimum yield means the time required to produce a maximum of the total gas because obtaining the remainder of the gas is not economical (Mang and Li, 2009).

The design life of a fixed-dome biogas plant is approx. 20 years. The important aspects for the design of the plant are covered in detail in literature (Balasubramaniyam et al., 2008; Kossmann et al. 1999a; Kossmann et al. 1999b). These include measures against the cold such as insulation, protecting the ground water, capturing all the gas by having a tightly sealed construction, and countering internal gas pressure with a sufficient soil layer on top of the reactor.

2.2.7 User Criteria

The recommended criteria for households interested in implementing a biogas sanitation system are the following:

- Minimum one cow or buffalo in the compound.
- Sufficient space to construct the biogas system underground and for storage and management of the digestate.
- Commitment to proper operation and maintenance of the system.
- Commitment to reuse of the biogas (i.e. not letting it escape into the atmosphere) and digestate.
- Use of guidelines for digestate reuse in agriculture and application of hygienic practices.

2.2.8 Information Links for the Design and Construction of Biogas Digesters

Design and Construction Guidelines

- Details on the design, construction and maintenance of biogas digesters are given by Kossmann et al. (1999b) http://www.susana.org/images/documents/05-working-groups/wg03/recommended-reading/kossmann-1999-biogas-digest-vol2-application-and-product-development-gtz.pdf
- And Sasse et al. (1991) http://www.susana.org/images/documents/05-working-groups/wg03/recommended-reading/sasse-1991-improved%20biogas%20unit%20for%20developing%20countries.pdf

Technical drawings

- Links to technical drawings of the fixed-dome biogas digester are available through the SuSanA website. http://susana.org/lang-en/cap-dev/visual-aids-drawings/technical-drawings

2.3 Constructed Wetland Wastewater Treatment System

2.3.1 System Components

The complete schematic, showing the inputs, the system processes, and the outputs of the constructed wetland wastewater treatment system is shown in Figure 6. The input stream is combined domestic wastewater (toilet waste and greywater). A simplified sewer is used to take wastewater from the household(s) to an external treatment system where it is pre-treated in a septic tank before being processed in the constructed wetland. The treated effluent is used as a nutrient-rich irrigation water. Faecal sludge that accumulates in a septic tank over time has to be removed after some years and can be used as a soil conditioner. Alternatively, a septic tank can be made for each participating household[16] from where the effluent can be taken via a simplified sewer directly to a constructed wetland (not shown in schematic).

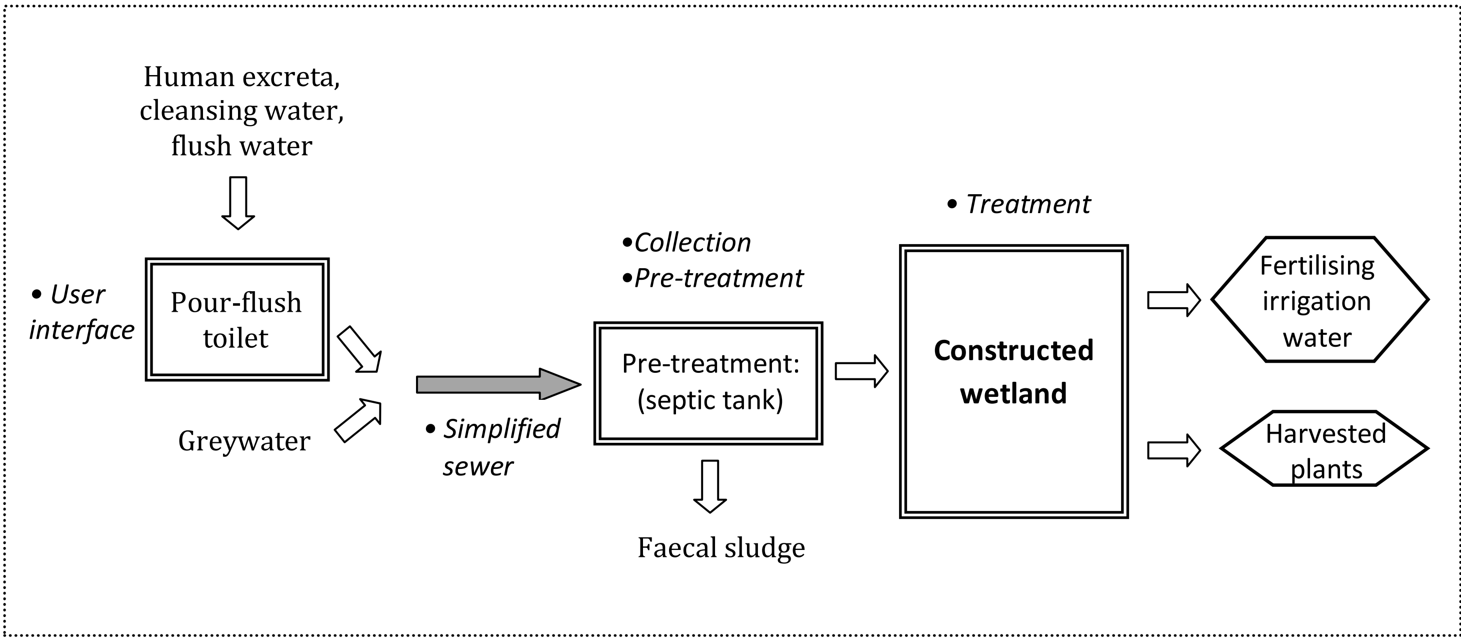

Figure 6: Schematic of the constructed wetland wastewater treatment system.

2.3.2 Description

The constructed wetland treatment system has been proposed in order to treat the complete wastewater of households, i.e. toilet effluent as well as greywater from bathing, washing clothes and kitchen sinks. Constructed wetlands can be designed for any scale of treatment, from individual households to complete communities. However, in the case of the Navin Well-Field Project Area, they have been envisioned for the clusters of newly constructed houses with little yard space for their own individual system. The wastewater would be transported from a group of participating households

[16] if space is available to make the septic tank and if a tanker can reach the septic tank for emptying out accumulated sludge after every few years.

or at least 15 adult users (for economies of scale) via a localised, simplified sewer line and treated collectively in an external constructed wetland treatment system.

The simplified sewer system is not looked at in this report, and relevant links are given in Section 2.3.8. To summarise, a simplified sewer consists of shallowly-buried plastic pipes, low-cost cleanouts instead of frequent and costly manholes, and a minimum number (if any) of lift stations. The sewer collects all household wastewater in small-diameter pipes laid at fairly flat rates. It is designed less conservatively than conventional sewerage systems to reduce costs but still accounts for transport of grit and solids (Akinyemi, 2008).

Pic. 27: A wetland under construction in Bayawan, Philippines (source: GTZ).

A constructed wetland is an engineered system that copies the purification functions of a natural wetland to treat contaminants in wastewater. While the essence of the system is the wetland structure, the system includes a pre-treatment or primary treatment step to reduce the level of solids in the effluent that can cause blockages in the wetland and reduce its purification capacity (Muench, 2009b).

In larger scale wetland plants, a septic tank is not needed where a ‘french system’ is used. This is a two-stage vertical flow system in which the first stage is for pre-treatment, and plants have been known to be functioning since 30 years. For the smaller scale of 15 adult users, however, a septic tank is recommended (pers. comm. Jan. 11, 2010, C. Platzer).

IWA (2000) describes a wetland as “a complex assemblage of water, substrate, plants (vascular and algae), litter (primarily fallen plant material), invertebrates (mostly insect larvae and worms) and an array of microorganisms (most importantly bacteria)”. Numerous and often interrelated mechanisms take place in this set-up to treat wastewater (IWA, 2000).

Some requirements are necessary to be able to use constructed wetlands to treat domestic wastewater. Constructed wetlands are low-rate treatment systems and therefore have a high space requirement. They need enough incident light to allow photosynthesis to take place because plants play an essential role in the system. Temperatures should not be too low as biological activity reduces significantly with lower temperatures. However, designs can be adjusted for cold climates (Muench, 2009b).

There are two main types of constructed wetlands:

- Free water surface (FWS)
- Subsurface flow (SSF)

The following excerpts describing the two types of constructed wetlands in this section have been taken from Muench (2009b). In FWS constructed wetlands, water flows **on top** of the soil medium (with a "free surface"), whereas SSF systems are designed to keep the water level **below** the top of the soil or gravel substrate.

A typical FWS constructed wetland (Figure 7) has emergent macrophytes and is a shallow lined basin or sequence of basins, containing 20 - 30 cm of rooting soil, with a water depth of 20 - 40 cm. These wetlands are similar in appearance to natural marshes. The wastewater flows above the ground exposed to the atmosphere. Incoming wastewater containing particulate and dissolved pollutants slows and spreads through a large area of shallow water and emergent vegetation. The depth of soil where the plants are rooted should be at least equal to the maximum possible root penetration (at least 0.2 - 0.3 m) which is necessary for the plant species chosen.

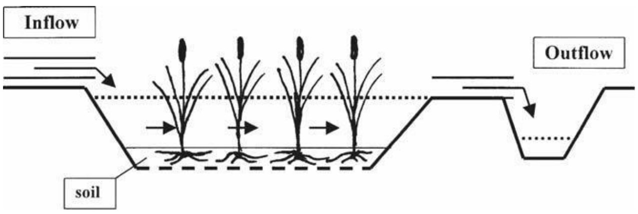

Figure 7: Schematic cross-section of a free water surface constructed wetland (source: Morel and Diener, 2006).

The SSF constructed wetlands are further classified according to the direction of water flow – horizontal or vertical. Water flows inside a layer of sand, gravel or soil (60 - 80 cm). In contrast to the FWS wetlands, the substratum contributes to the treatment processes by providing a surface area for microbial growth and supporting adsorption and filtration processes. This effect results in a lower area demand and generally higher treatment performance per area than FWS constructed wetlands. Furthermore, no mosquito breeding is expected by avoiding surface ponding.

Horizontal flow SSF systems are so named because the wastewater is fed in at the inlet and flows slowly through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone. Here, it is collected before leaving via level control arrangement at the outlet (Figure 8). The inlet zone is filled with small rocks or coarser gravel. Together with multiple vertical riser pipes, this ensures that the wastewater is distributed equally over the entire width and depth of the wetland.

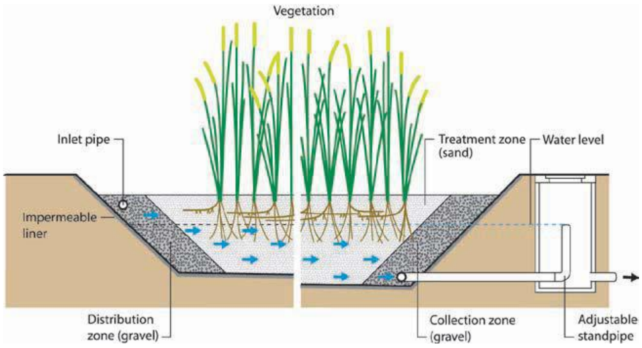

Figure 8: Schematic cross-section of a horizontal flow subsurface flow constructed wetland (source: Morel and Diener, 2006).

Vertical flow SSF systems become more popular than horizontal flow constructed wetlands when there is a space constraint as they have a higher treatment efficiency. Water is pumped on the surface and then drains down through the filter layer which consists of coarse sand or fine gravel (Figure 9).

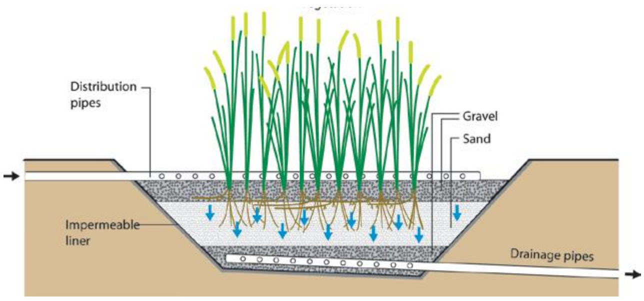

Figure 9: Schematic cross-section of a vertical flow subsurface flow constructed wetland (source: Morel and Diener, 2006).

The plants used in all the constructed wetland systems except the vertical flow SSF system need to be able to tolerate continuously water-saturated soil conditions (anaerobic soils). The types of plants are mainly emergent plants, such as reeds (this is the most common plant used, for example: *Phragmites australis* – the "common reed"); other helophyte species like cattail, rushes, sedges; and bamboo. Floating plants such as water hyacinth and duckweed are also found in the FWS constructed wetlands.

In the vertical flow SSF constructed wetland, the substratum is not always full of water and therefore almost all plants can be used which have high root growth in the upper 10 cm and have the ability to live with high nutrient water (almost all plants can) with a hydraulic load of up to 200 mm/d[17] (normally about 80 mm/d). In this system, C4[18] plants also do well, such as Vetiver grass (*Chrysopogon zizanioides)* (pers. comm. Jan. 11, 2010, C. Platzer). Vetiver grass is used for fodder, to make mats, and to make perfumes, essential oils, and medicines (Wikepedia, 2009 and Rämi, 2002).

[17] This would be a very very heavy rainfall but in a very absorbent soil.
[18] C4 refers to a particular pathway of carbon fixation in photosynthesizing plants.

Table 4 shows a general comparison of the FWS and SSF constructed wetlands. The decision on the type of wetland most appropriate for the Navin Well-Field Area should be made by the wetland consultant in conjunction with the participating households. The notable advantages of the SSF construction are less land area required, higher cold tolerance and no nuisance of mosquitoes. On the other hand, the FWS has lower operation and maintenance costs, and pumps would be needed for the vertical flow SSF.

Table 4: Comparison between free water surface and subsurface flow constructed wetlands.

	Free water surface constructed wetlands (FWS CWs)	Subsurface flow constructed wetlands (SSF CWs)
Advantages	• Lower installation costs (however, one must consider the greater land area needed) • Lower operation and maintenance costs • Simpler hydraulics • Open water areas (provides wildlife habitat including a high biodiversity) • High effectiveness in removal of suspended solids	• Higher removal efficiency per area (less area required per person) compared to FWS CW • Higher cold tolerance because of insulation through the upper media layer. More suitable in cold/boreal and temperate climate zones • No or minimal odour and mosquito problems • Higher number of suitable emergent plant species that can be chosen.
Dis-advantages	• Lower removal efficiency per area (more area required); this is a very land intensive system • Lower cold tolerance (more suitable in warmer climates) • Potential problems with odours and mosquito populations • Wastewater is exposed to potential human contact • Higher evapo-transpiration rates (increases pollutant concentrations especially in warmer climates)	• Higher construction costs, mainly caused by the substrate media (can be offset by less area requirement) • Higher operation and maintenance costs • More sensitive to elevated concentrations of suspended solids (clogging effects at the inlet zone)

2.3.3 Treatment Processes

The treatment processes in the constructed wetland wastewater treatment system comprise a pre-treatment step and the main purification processes in the wetland.

Adequate pre-treatment is important because the inlet zone of a FWS system and the filling medium of a SSF system can be clogged (Wallace and Knight, 2006). In the SSF especially, accumulation of solids reduces the treatment efficiency drastically by reducing the free pore spaces. Through pre-treatment with screens or a septic tank, suspended solids and larger particles (including toilet paper and other rubbish) as well as some organic matter can be removed.

The constructed wetland systems are usually designed for removal of suspended solids, organic matter and nutrients (nitrogen and phosphorus). The general treatment mechanisms in the systems include (IWA 2000):

- settling of suspended particulate matter,
- filtration and chemical precipitation through contact of the water with the substrate and litter,
- chemical transformation,
- adsorption and ion exchange on the surfaces of plants, substrate, sediment and litter,
- breakdown and transformation and uptake of pollutants and nutrients by MOs and plants, and
- predation and natural die-off of pathogens.

Treatment in free water surface constructed wetlands

The following excerpts in the rest of this section have been taken from Muench (2009b). In a FWS, the shallow water depth, low flow velocity, and the presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels, ensure plug-flow conditions. However, the major component concerning wastewater treatment is performed by microorganisms attached to the submerged portions of the plants. Thus, the physical presence of the plant tissues together with a complete vegetation canopy is more important than the composition of the wetland plant species themselves. Dense emergent vegetation covers a significant fraction of the surface, usually more than 50%.

FWS constructed wetlands typically have aerated zones, especially near the water surface because of atmospheric diffusion, and anoxic[19] and anaerobic[20] zones in and near the sediments. In heavily loaded FWS wetlands, the anoxic zone can move quite close to the water surface. These different zones host various types of microorganisms that help to process the wastewater.

Treatment in subsurface flow constructed wetlands

The substratum provides the support and attachment surface for microorganisms able to anaerobically (and/or anoxically if nitrate is present) degrade the organic pollutants Phosphorus is adsorbed and can be implanted in the plant growth of the constructed wetland. The substratum also acts as a simple filter for the retention of influent suspended solids and generated microbial solids, which are then themselves degraded and stabilised over an extended period within the bed.

The provision of a suitably permeable substrate in relation to the hydraulic loading to eliminate surface ponding is the most elaborate component of the subsurface flow systems. This factor is responsible for most treatment problems when permeability is not adequately catered for.

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[19] Oxygen is available for microorganisms in the form of nitrate.
[20] No oxygen is available.

Horizontal flow (HF-SSF)
The pre-treated wastewater flows continuously and horizontally through a porous soil medium where the emergent plant vegetation is rooted. The wastewater is purified through contact with the surface area of the soil particles and the roots of the plants. Plants provide appropriate environments for microbial attachment, growth and transfer of oxygen to the root zone. Organic matter and suspended solids are removed by filtration and microbial degradation in aerobic, anoxic and anaerobic conditions.

Vertical flow (VF-SSF)
The treatment for VF-SSF constructed wetlands is characterised by intermittent loading and resting periods where the wastewater percolates vertically through the unsaturated substrate. The intermittent and batch loading enhances oxygen transfer and higher rates of nitrification (transformation of ammonia to nitrate) in comparison to HF-SSF constructed wetlands. An almost complete nitrification is commonly reported with an efficiency rate of ammonia removal exceeding 90%. On the other hand, since VF-SSF do not provide much denitrification (transformation of nitrate to nitrogen gas), rather low total nitrogen removal rates are achieved.

2.3.4 Product Handling

Constructed wetlands treat wastewater to a standard fit for discharge to surface water or fit for various reuse applications according to WHO guidelines (WHO, 2006). The most common type of reuse is for irrigation. The nitrogen and phosphorus nutrients remaining in the effluent from the treatment system have a fertilising effect for crops. Relevant guidelines must be followed to ensure this practice is hygienically safe.

Pic. 28: Olive trees being irrigated with treated effluent (source: GTZ).

2.3.5 Operation and Maintenance

Whilst constructed wetlands are "natural", low-tech systems they still require adequate maintenance (Muench, 2009b). Tasks common to all types of constructed wetlands are given below[21]:

- Regular checking of:
  - pretreatment units
  - inlet structures
  - outlet structures
  - any pumps
- Inspection of wetland vegetation for disease, insects, etc. and proper treatment as required.
- Attention should be given to weeds and predatory plants until the wetland vegetation is fully established.
- Harvesting of plants should be done if required (whether plants from constructed wetlands should be harvested regularly or not is a question of debate).

If maintenance is ignored, the following consequences will be seen sooner or later:

- Uneven flow distribution
- Local overloading and odour
- Deterioration of treatment efficiency.

2.3.6 Design Information

The simplest design parameter for constructed wetlands is the area required per person. To give an indication of wetland size, Table 5 shows general design values based on municipal wastewater in the Netherlands (Muench, 2009b). Although the wastewater production in the Navin Well-Field Area is much lower (estimated 50 L/cap/d) and the organic load is not known, these figures can be used as the upper benchmark.

Table 5: Rule of thumb design values for different types of constructed wetlands treating municipal wastewater (Muench, 2009b).

Constructed wetland type	Design parameter (m^2/EP[22])
FWS	5-10
HF-SSF	3-5
VF-SSF	2-3

The expected design life of a constructed wetland is 25-30 years (sedimentation of the suspended solids and the sludge production in the constructed wetland are important factors of lifetime limitation) (Muench, 2009b).

[21] More specific information for SSF constructed wetland can be found in the (Muench, 2009b).
[22] 1 EP = 1 Equivalent Person = 60 gBOD/cap/d = 120 L/cap/d – these figures are valid for municipal wastewater in a country like the Netherlands.

Some important aspects in designing a constructed wetland are as follows (Muench, 2009b):

- All constructed wetlands should be built with an impermeable liner (plastic) or native soil material like clay at the bottom to prevent possible contamination of the groundwater.
- The slope at the bottom of the wetland should be:
  - 0.5% or less for FWS systems
  - 2% or less for HF-SSF systems
- For the selection of plants (macrophyte species), the following points can be made:
  - It is recommended to use local, indigenous species and not to import exotic, possibly invasive species.
  - Plants should have high biomass production, an extensive root and rhizome system and should be able to withstand shock loads and short dry periods.
- Constructed wetlands are sensitive to precipitation and evapo-transpiration because of their large surface areas. This needs to be considered in the water balance.

Pic. 29 - 30: *Left.* A newly planted constructed wetland. *Right.* Old constructed wetland (source: GTZ).

2.3.7 User Criteria

In light of the requirements for making a constructed wetland and maintaining the system, the following criteria should be met by households wanting to participate in the system:

- Identify other households in the neighbourhood (in order to have wastewater from at least 15 adults) to participate in the treatment system.
- Cooperate with consultant in identifying type of constructed wetland.
- Identify and obtain land required for the constructed wetland.
- Work together with other participating households in decision-making and task sharing.

- Have a commitment to maintaining the pre-treatment structure and the wetland and associated parts in the long-term (e.g. plants, pipes, pumps).
- Facilitate reuse of treated effluent for agricultural purposes following reuse safety guidelines.

2.3.8 Information Links for the Design and Construction of UDDTs

Design and Construction Guidelines

- Material from Professor Duncan Mara (Leeds university, UK)- expertise knowledge with design details for alternative sewer systems.
  www.personal.leeds.ac.uk/%7Ecen6ddm/MProdIndex.html

Technical drawings

- Several links to technical drawings of constructed wetlands are available through the SuSanA website.
  http://susana.org/lang-en/cap-dev/visual-aids-drawings/technical-drawings

Videos

- A video link to a wetland treatment system in Bayawan, Philippines.
  http://www.susana.org/lang-en/videos/wetland-treatment-in-bayawan-philippines

2.4 Septic Tank with Off-site Subsurface Infiltration Wastewater Treatment System

2.4.1 System Components

The complete schematic, showing the inputs, the system processes, and the outputs of the septic tank with off-site infiltration wastewater treatment system is shown in Figure 10. The input stream is combined domestic wastewater (toilet waste and greywater). A septic tank is constructed for each household to pre-treat the wastewater. Faecal sludge that accumulates in the septic tank over time has to be removed after some years and can be used as a soil conditioner. The effluent from the septic tank is transported via a simplified sewer and disposed in infiltration trenches, which are located some distance away from the deep water wells. Alternatively, the combined wastewater from a group of households can be transported via a simplified sewer network to a single collective larger septic tank, followed by an infiltration system (not shown in the schematic).

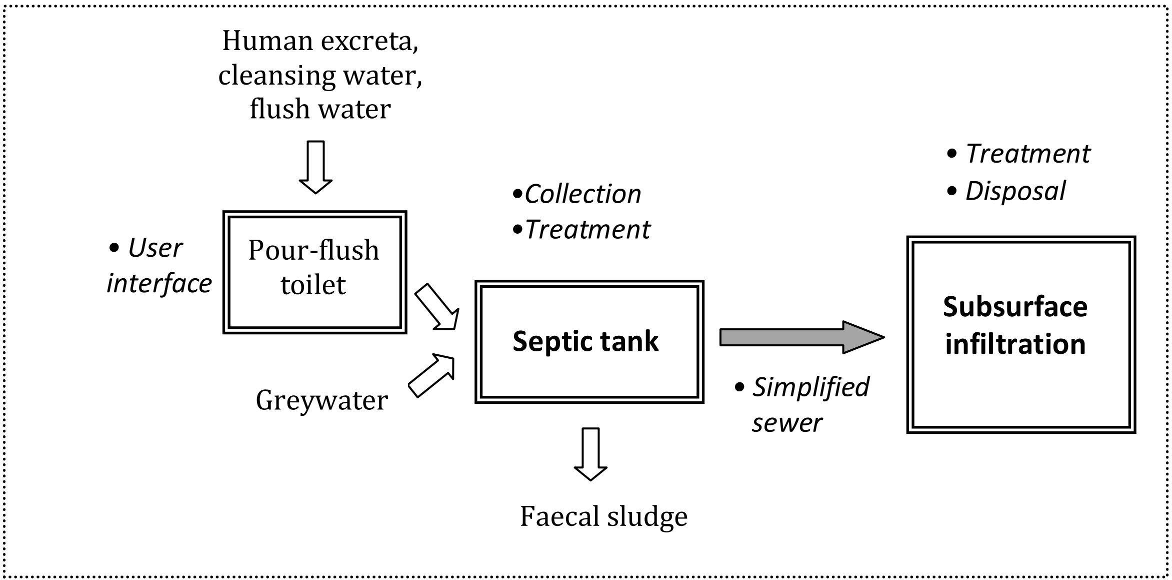


Figure 10: Schematic of the septic tank with off-site subsurface infiltration wastewater treatment system.

2.4.2 Description

The septic tank with an off-site subsurface infiltration wastewater treatment system has been proposed in order to treat the complete wastewater of households, i.e. toilet effluent as well as greywater from bathing, washing clothes and kitchen sinks. The septic tank is the first step in the treatment process and offers only partial treatment by separating solids from the liquid; both the settled faecal sludge and the continuous flow of effluent from the tank have to be treated further. In a single household system, the effluent is usually treated by using a soakage well or a form of subsurface infiltration. In the Navin Well-Field Project Area, it is not possible to use a soakage well because of the high ground water table and pollution risks, and therefore, the effluent has to be channelled off-site, using a simplified sewer line[23], and treated and disposed via subsurface infiltration. After discussion with GTZ-Rodeco, it was proposed that the subsurface infiltration should be at least 100 m away from the deep water well zone.

Septic tank

The following excerpts describing a septic tank have been taken from Eawag's Compendium of Sanitation Systems and Technologies (Tilley et al. 2008).

A septic tank is a watertight chamber made of concrete, fibreglass, PVC or plastic, for the storage and treatment of blackwater and greywater. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate. A septic tank should typically have at least two chambers. The first chamber should be at least 50% of the total length and when there are only two chambers, it should be 2/3 of the total length. Most of the solids settle out in the first chamber. The baffle, or the separation between the chambers, is to prevent scum and solids from escaping with the effluent. A T-shaped outlet pipe will further reduce the scum and solids that are discharged.

Liquid flows into the tank and heavy particles sink to the bottom, while scum (oil and fat) floats to the top. With time, the solids that settle to the bottom are degraded anaerobically. However, the rate of accumulation is faster than the rate of decomposition, and the accumulated sludge must be removed at some point. Generally, septic tanks should be emptied every two to five years, although they should be checked yearly to ensure proper functioning.

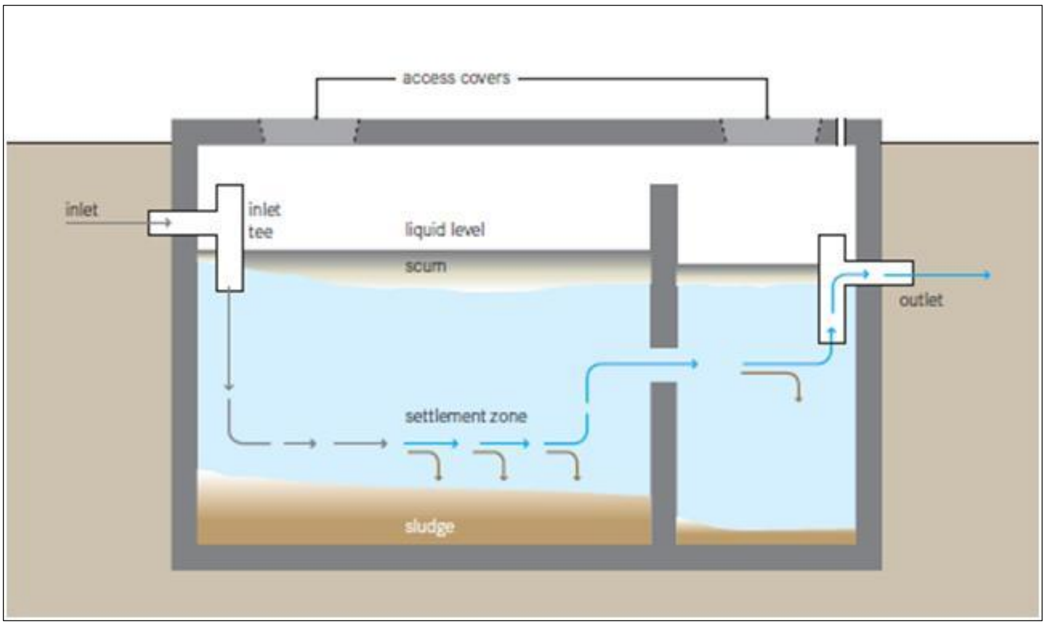


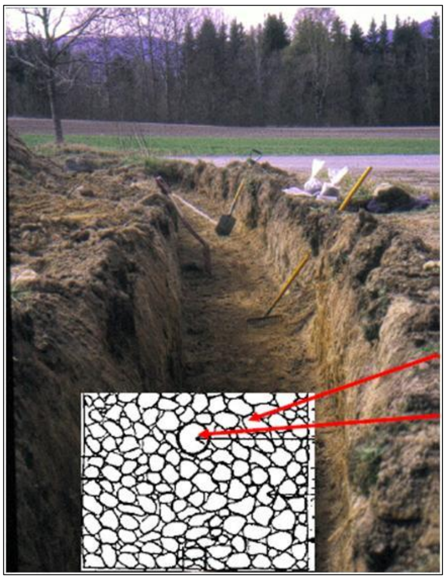
Figure 11: A schematic of a two chamber septic tank (source: Tilley et al., 2008).

[23] See Section 2.3.2.

Sub-surface infiltration systems

Subsurface infiltration requires soils with good absorptive capacity to effectively dissipate the effluent, which should be feasible in the largely gravel subsoil of the project area. In a typical infiltration system, a network of perforated pipes is laid in underground gravel-filled trenches that help to drain the effluent. Such trenches are 0.3 to 1.5 m deep and 0.3 to 1 m wide. The pipes are placed 15 cm below the surface to prevent effluent from surfacing (Tilley et al., 2008). Jenssen (2008a) points out various forms of subsurface infiltration. The methods include the following:

- The standard trench
- Sand filter
- Mound
- Aeration bed



Pic. 31: An infiltration trench in sandy soil (source: Jenssen, 2008a).

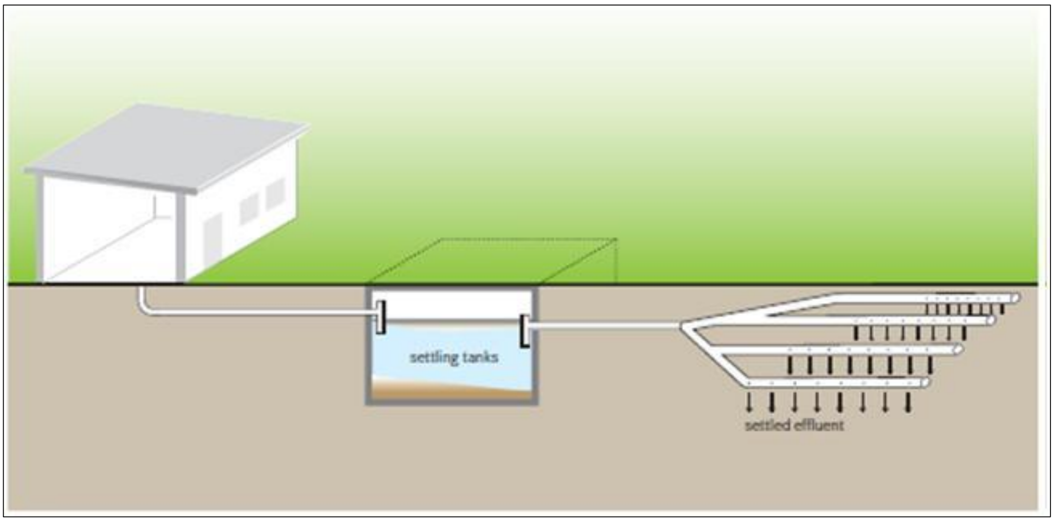


Figure 12: A subsurface infiltration system for household wastewater (source: Tilley et al., 2008).

2.4.3 Treatment Processes

As stated earlier, the main mechanism of treatment of wastewater in a septic tank is solid-liquid separation. The solids are then partially degraded anaerobically with the passage of time. Generally, the removal of 50% of solids, 30 to 40 % of biochemical oxygen demand (a term used to measure the biodegradable organic matter in wastewater) and a 1-log removal of *E.coli* can be expected in a well designed septic tank although efficiencies vary greatly depending on operation (Tilley et al., 2008).

The principal treatment of the septic tank effluent in a subsurface infiltration system occurs by physical filtration and by biological degradation of the organic substances in the effluent (Jenssen, 2008a).

The faecal sludge removed from a septic tank has to be treated further to reduce the level of pathogens in it before reusing it on agricultural fields. The local method of mixing such matter with soil and leaving it for a few months to dry in the sun should be sufficient to significantly reduce the pathogens in the sludge.

2.4.4 Product Handling

This wastewater treatment system is primarily a disposal system in which the effluent is not reused. The faecal sludge removed periodically from the septic tank however can be used as a soil conditioner after a treatment phase. In line with the multi-barrier approach, hygienic practices and application guidelines (crop and time restrictions) should be followed when handling the material and using it on agricultural fields.

2.4.5 Operation and Maintenance

The septic tank with off-site subsurface infiltration wastewater treatment system needs minimum operational oversight. The maintenance requirements for the system are given below (Tilley et al., 2008):

Septic tank

- Checking of the tank to ensure that it is water tight.
- Monitoring the level of scum and sludge to ensure that the tank is functioning well.
- No discharge of harsh chemicals into the tank.
- Removal of faecal sludge every few years (time interval depends on the design value).

Subsurface infiltration

- Cleaning or replacement of clogged pipes (this should take many years with a well functioning septic tank).
- The area above the infiltration fields should be kept clear of plants or trees and there should be no traffic that may crush the pipes and compact the soil.

2.4.6 Design Information

Eawag's Compendium of Sanitation Systems and Technologies (Tilley et al., 2008) states the following about the design of a septic tank. The dimensions depend on the number of users, the amount of water used per capita, the average annual temperature, the sludge pumping frequency and the characteristics of the wastewater. The retention time should be designed for 48 hours to achieve moderate treatment. Moreover, septic tanks must have a vent to release the gases formed during anaerobic breakdown.

The loading rate of effluent from a septic tank into a subsurface infiltration system and hence the size of the infiltration area depends on the soil hydraulic capacity, infiltration rate and purification ability (Jenssen 2008b). Furthermore, the system will have a higher treatment performance if the biologically active top soil layer is utilised and if the design promotes air flow through the effluent infiltrating area in the subsoil (Jenssen 2008a).

2.4.7 User Criteria

The recommended criteria for households interested in implementing a septic tank with subsurface infiltration wastewater treatment system are the following:

- Identify and obtain land required for the subsurface infiltration system.
- Have sufficient space for an underground septic tank.
- Commitment to proper maintenance of the system.
- Follow guidelines for faecal sludge treatment and reuse in agriculture and apply hygienic practices.

3.0 FEEDBACK WORKSHOP WITH COMMUNITY

After assessing the situation in the Navin-Well Field Area, four alternative sanitation systems were selected which would not contaminate the ground water and also meet other criteria for a sustainable system (see Section 1.5 for the criteria and Section 2 for the selected systems). The final decision to implement a new sanitation system has to however be taken by the participating households so that the system meets the users' needs and so that they take ownership of it and are able to operate and maintain it. Therefore, a workshop was held with the community; the purpose was to review and discuss the sanitation situation and possible alternatives for sanitation. The workshop was facilitated by the GTZ-Rodeco engineering team, myself and a lady translator.

The workshop was held in the local mosque. Participants consisted of representatives from most of the 42 target households and some people from the wider community[24]. With consent of the village elders, both men and women attended the workshop; a curtain was used to divide the two groups so that they could hear each other but not see each other. The proceedings were conducted as follows:

1) A framework for assessing a sanitation system was presented visually using chart papers which were pasted on the walls. The framework consisted of sustainability criteria (health, environment, economics, technical feasibility and culture), scale of impact (household, neighbourhood, village and district), and groups of people (handicapped, elderly, children, men and women).

2) The participants were asked to assemble into groups and assess the advantages and disadvantages of the two existing sanitation systems - i.e. the raised-vault 'simple latrine' and the pour-flush, sewage well system - as well as the alternative system proposed by them during the preliminary discussions - i.e. the pour-flush, completely sealed holding tank system (see Table 6). They were reminded to refer to the assessment framework for the exercise.

3) The four improved, alternative sanitation systems were then shown to the participants using a pictoral (since many participants were illiterate) power point presentation. Each system was described and the requirements for each system were highlighted. A short video clip on the construction of the UDDT was also shown.

4) Feedback of the four alternative systems was obtained.

As Table 6 shows, the advantages and disadvantages listed by the participants for the existing sanitation systems were similar to those that had been identified in the preliminary discussions. The participants also mentioned the same benefits of a holding tank as they had identified in earlier discussions - ground water protection and no flies and smell during use. They, however, also realised that the holding tank option did not solve all the issues faced currently. For example, as with the sewage well, smell and flies would still have to be tolerated when emptying out the holding tank and the families

[24] The wider community was also involved so that they could understand the alternatives for future replication (either by their own initiative or potential project support).

would have to pay for this procedure regularly. Moreover, some participants pointed out that the sewage removal truck would not be able to have physical access to all households and it would not be possible to empty out the holding tank.

Table 6: Advantages and disadvantages listed by the workshop participants of the two existing sanitation systems and the community proposed holding tank alternative.

Type of Sanitation	Advantages	Disadvantages
Existing systems: 'simple latrine' and pour-flush toilet with sewage well	• Valuable for land, vegetables and agriculture • No flies and smell during operation of the pour-flush toilet with sewage well	• Cost of emptying out (if labour or truck are used) • Bad smell and flies during operation of the 'simple latrine' • Bad smell for neighbours and home and flies during emptying-out procedure • Unhygienic material being emptied out • Infiltration of pollutants into ground water and pollution of shallow water wells • Need sufficient distance between the pit and soakage well because it should be 15 m from the drinking well. • Bad for the environment
Community recommended system: pour-flush toilet with completely-sealed holding tank	• No pollution of groundwater • No flies and smell during use ***Recommendation-*** *holding tank should be built large enough so that it only has to be emptied out once a year*	• Cost of emptying out • Negative effect on the environment after emptying out • The sewage removal truck cannot have physical road access to all households • Bad smell for neighbours and home and flies during emptying -out procedure

The men and women listened keenly to the presentation of the four alternative sanitation systems, especially the UDDT and the biogas systems. The concept of biogas production was new for the community and they were interested to know about the potential as a cooking fuel. Notably, this time the men did not voice a negative reaction to the UDDT and were curious about the workings of the system. There was a concern whether children would be able to use the UDDT and the facilitators confirmed that this was not a problem.

One of the men raised the point that even if the UDDT would be suitable for and properly used by a household, family guests would not know how to use the system. To this concern, a woman replied that guests would have to be informed about using the toilet and in this way the neighbourhood and other people would also soon learn about this new system. The facilitator added that if the faecal chamber in the UDDT did become too moist at times, sit could be remediated by adding extra dry matter.

Pic. 32: Men participants in the feedback workshop (source: GTZ-Rodeco).

Pic. 33: Presentation on assessment framework (source: GTZ-Rodeco).

Pic. 34: Group work (source: GTZ-Rodeco).

The feedback session of the four alternatives (i.e. the final session of the workshop) had also been planned as an interactive group work. The participants would be allocated to four groups, one for each of the systems, to assess advantages and disadvantages, and they would then discuss these with the whole forum. All the women worked together as one group analysing the UDDT and shared their findings in the plenary. The men, however, had no discipline or patience for this exercise. They could not be urged to carry out a systematic assessment with a discussion in a plenary of the remaining three systems; rather they became side-tracked about issues of land and benefits.

The advantages and disadvantages identified by the group looking at the UDDT (all women) are given below. The forum as a whole agreed to this analysis.

Advantages of UDDT:

- No smell
- No flies
- No pollution of shallow water wells
- Reduced illness
- Reduced flies
- Less rubbish because ash from the kitchen is used
- Benefits to agriculture- increase production, strengthen soil
- Improved hygiene
- Better toilet culture

Disadvantages of UDDT:

- Cost of construction (possibly)
- Availability of space

The response to the other three systems, voiced by the men, can be summarised as follows. The participants who had space in their homes and livestock that would contribute manure were excited about the biogas option. It appeared that the men who did not belong to households with these conditions were resentful of not falling into this category. Another issue was that of land. The constructed wetland and septic tank with infiltration trenches would require external pieces of land; the new settlers did not have land and felt they could not negotiate with surrounding farmers for obtaining land. The most notable issue was that the men were not interested in any system in which they would have to work together with other households. Each person wanted an individual household system, and therefore they were not willing to consider the constructed wetland as an alternative system.

4.0 RECOMMENDATIONS FOR NEXT STEPS

4.1 Implementation Plan

A plan is presented in Table 8, which shows the major activities in order to implement improved sanitation systems in the Navin Well-Field Project Area. The logic of the plan is to first establish model UDDT and biogas systems with active households so that the project team can focus on making them into well-functioning demonstration systems. These systems would then serve as a learning base and a motivation for households in establishing the remaining sanitation units. It is foreseen that only one or two wetland systems will be needed and hence a model period is not necessary.

Important elements to note in the implementation plan are as follows:

- **Stakeholder mapping and long-term support mechanisms**
  Institutional aspects are important for the sustainability of sanitation systems so that the participating households can access support in the long-term to operate and maintain and benefit from their systems. Furthermore, institutional mechanisms are essential for scaling up pilot measures and for supporting self-replication initiatives and demonstration effects.

  A first step in developing institutional aspects is undertaking a stakeholder mapping and involving the stakeholders from the planning stage onwards so that their feedback can be incorporated in the project.

  The stakeholders that are needed for the long-term success of the project need to be especially developed and involved during project implementation. In particular, this consists of market players and government agencies. Service providers need to be developed in the market who can supply hardware and technical expertise needed for the establishment and upkeep of a system. A government agency should be developed as the long-term regulatory and support institution. The most appropriate agency should be selected by GTZ-Rodeco. Meanwhile, in the implementation plan, the Department of Urban Development has been considered as the proxy long-term support institute for sanitation systems and is therefore listed as a key player in the activities.

- **Exposure trips**
  Exposure trips are a motivational tool and an effective means of helping stakeholders to adopt a new technology. They are also a way of forming support networks. The organisation Voice of Women Organisation (see Section 2.1.8) has made UDDTs in Herat Province, and it has been reported that some of the beneficiary families are also using the treated excreta as fertiliser. It is recommended that the GTZ-Rodeco project team should visit these UDDTs and if they are functioning well, an exposure trip should be arranged for the well-field project participants to see these UDDTs in operation.

  An exposure trip is particularly recommended for the biogas sanitation system because it is a complex system that people have generally not seen before. An exposure trip would especially demonstrate to potential service providers the market requirements of the construction and maintenance aspects, to participating households the operational, maintenance and reuse aspects, and to permanent institutions the long-term support elements needed. An exposure trip would be most convenient to a country in the region with vast biogas experience such as India, Nepal or China. The latter two countries also have much experience of establishing biogas plants in cold climates.

- **Consultant expertise (see Table 7)**
  Expert consultants are recommended for the biogas system and the constructed wetland system. Millions of household biogas plants exist worldwide. However, the success of the plant depends on suitable design and critically, on proper construction (see Section 2.2.4), which should be carried out and monitored by a consultant. The consultant can simultaneously train local expertise in all necessary aspects of system design, construction, operation and maintenance.

  It is recommended that a consultant be used to select and design the most appropriate form of constructed wetland and pre-treatment system (see Section 2.3), keeping in viewing the local capacity for upkeep of the system, and train relevant stakeholders in the long-term maintenance of the system.

  A consultant is not thought to be necessary for the UDDT because it is based on simple design assumptions and can be constructed easily with the assistance of a civil engineer. Similarly, the design assumptions for infiltration trenches are also relatively simple and a septic tank is a conventional system and construct-ion element.

While the timeline for the project implementation plan is until August, it is recommended that the target households be actively followed up beyond this period, for at least two years, by the long-term institutional support partner in order to ensure the long-term viability of the systems.

Table 7: List of experts in wetland and biogas systems.

Name	**Email**	**Company**	**Expertise**
Martin Wafler	martin.wafler@seecon.ch	Seecon Gmbh, Switzerland	wetland
Christoph Platzer	chr@rotaria.net	Rotaria del Peru	wetland
Bahadar Nawab	bahadar.nawab@yahoo.com	Comsats University, Pakistan	wetland
Heinz-Peter Mang (with a team of 3 out of: Pravinjith, Nanchoz Zimmermann, Kalidas Neupane, Prashun, Xu Chao, and Chen Langnan)	H-P Mang: hpmang@gmail.com, heinzpeter.mang@cimonline.de	CIM Integrated Expert at USTB China Node Sustainable Sanitation, Beijing, China	biogas

Table 8: Implementation plan showing activities, month of implementation, the role of the GTZ-Rodeco project team and the participation of any other actors in the activities[25].

	Activity	J	F	M	A	M	J	J	A	Role of Project Team	Other Actors
	Finalise preliminary selection of sanitation system for each target household	■								Facilitation	Target hhs
	Identify model households for 3 biogas units and 4 UDDTs	■								Identification	Target hhs
	Undertake stakeholder mapping	■								Identification	
	Conduct a feedback seminar to introduce objectives and sanitation systems to stakeholders	■								Implementation	Stakeholders
	Conduct stakeholder field visit to the sanitation systems						■			Implementation	Stakeholders
	Conduct hygiene campaign			■	■	■	■	■	■	Facilitation	DACAAR (see Section 4.3)
UDDT	Dialogue with Agriculture Dept. about fertiliser demonstration trials using treated excreta in crop or vegetable production	■								Dialogue	Agriculture Dept.
	Visit UDDT project of Voice of Women Organisation and decide if it would be of value for an exposure trip to the project site	■								Assessment	VWO
	Exposure trip of UDDT target households, Agriculture Dept. and DoUD to VWO UDDT project areas (if useful)	■								Implementation	Target hhs, VWO, Agriculture Dept., DoUD[26]
	Finalise design for UDDT		■							Implementation	DoUD
	Construct 3 model UDDTs			■						Implementation	Target hhs, DoUD
	Monitor operation and maintenance of model UDDTs			■	■	■	■	■	■	Follow-up	Target hhs, DoUD
	Conduct crop or vegetable demonstration trails with urine application on plots in the target area						■	■	■	Implementation	Agriculture Dept., target hhs, DoUD
	Construct remaining UDDTs						■	■	■	Implementation	Target hhs, DoUD
	Monitor operation and maintenance and reuse perspective of all UDDTs						■	■	■	Follow-up	Target hhs, DoUD

[25] The abbreviations are as follows: hhs (households), UDDT (urine-diverting dehydration toilet), VWO (Voice of Women Organisation), DoUD (Department of Urban Development), ST (septic tank).

[26] The Department of Urban Development is considered here as the long-term support institution and is therefore a principal actor in the activities (the actual long-term partner should be selected by GTZ-Rodeco).

	Activity	J	F	M	A	M	J	J	A	Project Team	Other Actors
Biogas system	Undertake detailed feasibility for biogas system in all identified households			■						Implementation	**Biogas consultant** (may be possible via email)
	Select skilled workers (masons, gas suppliers etc.) from the market for training in construction, start-up and maintenance of biogas plants and supply of spare parts		■							Identification	Skilled workers
	Exposure trip of target households, DoUD representatives, and skilled workers overseas (India, Nepal or China) to see biogas system models			■						Implementation	Target hhs, skilled workers, DoUD
	Construct and start up 3 model biogas units with on-job training for skilled workers and operation and maintenance training for target hhs				■					Facilitation	**Biogas consultant**, skilled workers, target hhs, DoUD
	Follow up the model biogas systems in operation and construct and start up remaining biogas plants- lead by the trained skilled workers, with monitoring from consultant						■			Facilitation	**Biogas consultant**, skilled workers, target hhs, DoUD
	Follow up all biogas systems, conduct refresher training for skilled workers, and strengthen any weak links in system sustainability								■	Facilitation	**Biogas consultant**, skilled workers, target hhs, DoUD
	Monitor operation and maintenance and reuse perspective of all biogas systems					■	■	■	■	Follow-up	Target hhs, DoUD
Wetland system	Undertake detailed site feasibility and prepare wetland system design			■						Facilitation	**Wetland consultant**, target hhs, DoUD
	Finalise site and land arrangements for wetland system			■						Facilitation	Target hhs
	Construct, sewer, pre-treatment system and excavate site				■					Implementation	Target hhs, DoUD
	Complete wetland preparation, plant vegetation and start up the system					■				Facilitation	**Wetland consultant**, target hhs, DoUD
	Monitor wetland system						■	■	■	Follow-up	Target hhs, DoUD
ST-infiltrate	Make design for sewer, septic tank and infiltration trenches				■					Implementation	DoUD
	Identify area and finalise land arrangements for infiltration trenches					■				Facilitation	Target hhs, DoUD
	Construct sewer, septic tank and infiltration trenches						■			Implementation	Target hhs, DoUD
	Monitor system							■	■	Follow-up	Target hhs, DoUD

4.2 Sanitation Systems for School and Mosques

The target area close to the deep water wells has one school and two mosques. The premises of these institutions have the traditional 'simple latrine' and are contributing to groundwater pollution. Moreover, the five toilet cabins in the school are inadequate for the approximately 2,000 students. While this assessment focussed on sanitation systems for the households in the target area, the school was also visited shortly, and thus brief recommendations are given here. The toilets of the mosques were not looked at. Three sanitation systems could be suitable for the school (case studies are given on the website of the Sustainable Sanitation Alliance, www.susana.org, with such examples):

1) Double vault urine-diverting dehydration toilet system, with reuse of treated faeces and treated urine as fertiliser. Greywater treatment could be in a constructed wetland. Refer to the case study on a school in Hayanist, Armenia, on the SuSanA website.
http://www.susana.org/images/documents/06-case-studies/en-susana-cs-armenia-hayanist-school.pdf

2) Pour-flush toilet and biogas sanitation unit, with reuse of slurry as fertiliser and biogas as a fuel. Optionally, urinals for boys with reuse of treated urine as fertiliser, can also be added. Greywater treatment could be in a constructed wetland. Refer to the case study on DSK Training Institute, Gujarat, India on the SuSanA website.
http://www.susana.org/images/documents/06-case-studies/en-susana-cs-india-gurajat-navsarjan-dsk-2009.pdf

3) Decentralised wastewater treatment system (DEWATS)- pour-flush toilets attached to a series of biogas unit, anaerobic baffled reactor, anaerobic filter, horizontal flow wetland and storage pond- with reuse of biogas as fuel and effluent as irrigation water. Optionally, urinals for boys with reuse of treated urine as fertiliser, can also be added. Refer to the case study on Adarsh College, Badlapur, India, on the SuSanA website.
http://www.susana.org/images/documents/06-case-studies/en-susana-cs-india-badlapur-adarsh-school.pdf

4.3 Hygiene and Sanitation

Hygiene is a critical component of sanitation. Without hygienic behaviour, a toilet system cannot protect health. Discussion with the community on hygiene aspects of sanitation revealed that while people were aware of the link between hygiene and health, only about 10% of the village practised hand washing with soap. Therefore, it is recommended that hygiene education and awareness-raising be made a part of the sanitation efforts in the target households. Literature on hygiene aspects of sanitation can be found at http://www.susana.org/lang-en/working-groups/wg04.

In Herat, DACAAR (Danish Committee for Aid to Afghan Refugees) has several years of experience in carrying out hygiene campaigns. Their campaign targets a village for six months in which a husband and wife promoter team delivers hygiene messages to the people. They use household visits, the radio and also theatre programmes to motivate people in adopting hygienic practices. Families are also given hygiene tool kits (pers. comm. Engr Wali, DACAAR Herat). DACAAR could be a possible implementing partner for hygiene campaigns in the target area.

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