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Alternatives to Waterborne Sanitation – a Comparative Study – Limits and Potentials

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The study analyses the potentials and limits of alternatives to waterborne sanitation. It is based on a comparison between a waterborne sanitation system (WS) and a dry sanitation solution (DS). It suggests that the introduction of urine diversion dry toilets (UDDT) in Peru would enable water to be provided for 50% more inhabitants, a very important aspect for Peru which is heavily affected by climate change, with a predicted sharp decrease in water availability in future.
A cost comparison compares a situation of 10,000 households. The comparison is done from the point of view of a sanitation company, as the authors strongly believe that only an organised municipal sanitation service (whether or not privately operated) can assure a sustainable solution. The company would need to invest about US $1,038–US $1,227 per household for a waterborne system, while the dry sanitation system is estimated at US $935 per household.
A management service model is proposed, in which the sanitation company collects dried faeces and stored urine every three months. Operational costs are calculated to include transport, handling in a central plant, administration costs and education costs. Based on the actual water tariff in Lima, the dry system is calculated to give each household an advantage of US $1 a month.
In total, a very clear advantage for the DS can be shown and it is essential to implement large scale solutions in order to be able to optimise the proposed systems.
The comparison does not take into account economic advantages which could be generated by selling the urine. Based on the price of fertiliser in agricultural use in Lima and surrounding cities this saving would be about US $20 per household per annum. In the authors' view, the marketing of such products should not be done by the sanitation company but by agriculture organisations. An additional desert area of 160 ha could be irrigated by using all the saved or treated water in the DS model.

Introduction

Peru is one of the countries most affected by climate change, especially in the coastal desert area. This area makes up less than 15% of the total Peruvian territory, but is where 60% of the population live. The capital, Lima (8 million inhabitants) is situated in one of the world's driest areas, where 1.3 million inhabitants don't have access to the public water supply (MVCS 2006) and live with less than 25 litres (L) of water per day, and around 3 million people use latrines, which is not an adequate sanitation solution for urban areas.
A similar situation can be encountered in many Peruvian coastal cities. Officially 20% of the Peruvian wastewater passes through a treatment plant, but the reality is much worse, because the treatment plants often are not operated correctly, so that most of the collected wastewater (57%) is discharged almost untreated. Problems with water quality in rivers and costal areas are dramatically rising.

In the past, there have been attempts to introduce dry sanitation (DS) concepts in Lima, but they failed due to a series of problems, as described in Oswald & Hoffmann (2007). The main reasons were the absence of a sustainable management model, unresolved technical problems and the perceptions of the people who were expected to use the system, who regarded the urine diversion dry toilets (UDDT) as a temporary solution. It was very clear that even poor people in marginal settlements do not have the interest, time or patience to care for their toilets or to use the products. There was no interest in the ecological dimension, as people are only interested in a solution for their disastrous sanitary situation. The only solution they can imagine and are therefore interested in is the flush toilet.

Figure 1: Public latrine, typical sanitary “solution” in peri-urban settlements in Lima.
Source: P.Oswald

Figure 2: Until 2007 UDDT in Lima always mixed grey water with urine, but the infiltration often didn’t work properly.
Source: P.Oswald

Figure 3: This family already is prepared for connection to the water supply! As in this case, water flush toilets are always preferred.
Source: P.Oswald

A paper by Cordova & Knuth (2005) gives a very detailed analysis of possible failures in large scale implementation. The paper discusses each aspect in detail and points out that there is a high need for an effective sanitation *service* when it comes to large scale implementation. With a higher number of users, a system cannot rely on a voluntary service by users. Therefore, this paper is based on the assumption that the whole DS system has to be operated to a quality for the user which could be compared with a waterborne (WS) system. The term “quality” means, in this case, that the user receives the same service as in a wastewater system or at least the same as for waste collection. Speaking of “large scale” implementation, one has to see that Cordova & Knuth analysed cases with a maximum of 600 UDDT.

The only real large scale implementation the authors know of is in Durban where more than 60,000 UDDTs have been installed successfully and are operated by the local sanitation company (Gounden et al., 2008). In view of this, it is highly necessary to implement dry solution projects in various surroundings, in order to gather more experience which would go way beyond the theoretical approach put forward in this paper. Indeed, the aim of this theoretical approach is to encourage decision makers to take the “risk” of investing in real large-scale projects. In the case of desert areas such as Lima and the Peruvian coast, we do have a potential “win-win” situation. There will simply be no water for a long term waterborne sanitation, so this is the best opportunity to try this out.

The reality of waterborne sanitation in Peru

Every sanitation system operated by a sanitation company in Peru is a waterborne system. WS is regarded as the “permanent” solution whereas latrines are the solution for poor people and are considered symptomatic of a lower class service. The government of Peru is putting great effort into attaining the Millennium Development Goals (MDGs) and is implementing a series of sanitation systems all over the country. Almost all of these systems consist of a sewerage system, often a condominial system with wastewater treatment in lagoons or Imhoff tanks. These existing systems show serious operational problems. Figure 4 shows effluent from an overloaded wastewater lagoon. This effluent is used for agricultural irrigation. Figure 5 shows another typical situation; the sewer was deliberately blocked in order to provide an overflow into an irrigation channel for crop irrigation. Figure 6 shows a new social settlement in a suburb of Lima, where a WS with sewerage and a treatment plant was installed. After two years, there is still no connection to the public water supply, so that the families cannot use their WCs, and do not have any sanitary solution.

Figure 4: Effluent from a treatment pond system, being used for irrigation.
Source: H. Hoffmann

Figure 5: A blocked sewer, leading to raw wastewater from the city used for irrigation in agriculture.
Source: H. Hoffmann

Figure 6: Settlement in Lima with flush toilets (15 L per flush). But there is no water to use them.
Source: H. Hoffmann

Water saving technologies and water economising practices are almost unknown, so that in areas where water is available, consumption is about 200 L per household per day (lphd). Figure 7 shows a typical situation where water is wasted; most water-based toilets in Peru have almost permanent water loss due to a valve failure. Water loss in the public supply system is more than 40 % (SUNASS, 2008). Parks in the city centre are heavily irrigated (Figure 8), often with water of drinking quality. The use of grey water is not practised; often the very idea of reuse is rejected. From an economic point of view there is no interest in reuse, because the price of drinking water is very low, with a fixed charge of US $3-8 per month, and an additional US $0.30 for the first 20m³/month.

This situation discriminates against the poorest as there is not enough water to supply everyone with 200 l/d, and those who are not connected to the public system have to pay the highest prices (up to US $3.50 per m³) for water of dubious quality. The poor are therefore more affected by water-borne diseases caused by inadequate water and sanitation services.

Figure 7: Water loss due to malfunctioning of water valves.
Source: H. Hoffmann

Figure 8: Irrigation of parks in the city centre.
Source: H. Hoffmann

Figure 9: Grey water on the streets of settlements.
Source: H. Hoffmann

The necessary investments to achieve the sanitation MDG target for Peru by 2015 are calculated to about US $1.454 billion (MVCS, 2006), which is considered to be an almost impossible investment. These facts lead to the following conclusions:

- The situation especially in the highly populated but totally dry costal areas of Peru demands a sanitation system which reduces water loss and water consumption for transportation purposes to a minimum.
- Whatever sanitation system is adopted must avoid irrigation of farmland with raw or partially treated wastewater, and the discharge of untreated wastewater into rivers.
- Used water must have a quality which allows simple onsite treatment and guarantees the secure reuse of the treated water for local irrigation or infiltration, where possible, with grey water.

- The social situation in Peru demands a sanitation system with considerably lower investment and operation costs than the conventional solution.

The hypothesis is that a UDDT solution with an organised collection service and onsite grey water treatment or semi-decentralised grey water treatment, could be a promising alternative to the conventional waterborne solution. This study critically analyses this hypothesis.

The basic assumptions

As always when it comes to comparisons, the basic numbers and assumptions are fundamental. The following section tries to give as clear and comprehensive numbers as possible. The method of calculation will be given in each case, giving readers the possibility of repeating the calculation with their own example or with "better" numbers. The authors have tried always to use numbers that favour WS, with the aim of proving that, even under these conditions, our hypothesis is valid in the given situation that applies on the coast of Peru.

The example is given for a settlement, small city or suburb of about 40,000 inhabitants living in 10,000 households. As no UDDT solution currently exists for people living more than 3 floors up, this calculation does not apply to areas with a large amount of high-rise housing. The number of 10,000 households was chosen in order to approximate to large scale implementation. Basic water consumption was assumed to be 150 litres per capita per day (l/pe/d)[1] for the WS and 100 l/pe/d in the case of the DS.

Description of the dry sanitation solution

When implementing a dry sanitation solution, one has to offer a quality of sanitation which fulfils all the basic needs of the user. These can be described as a clean toilet without smell or flies, the possibility of having the toilet in the house, with integration into a regular bathroom (see Figures 10 & 11), and no handling of fresh faeces. With a total of 40,000 people, it cannot be expected that all users will be ecologically orientated or interested in putting effort into a sustainable sanitation solution. For this reason, a sustainable solution should not cause more work than a solid waste collection system. The authors believe that in the current situation, success of the DS concept only can be guaranteed when there is a strong incentive in favour of the DS solution. This is necessary until DS comes to be seen as equivalent to WS. Figures 10 and 11 show dry sanitation installations in bathrooms as examples of their general applicability.

Figure 10: Dry toilet integrated into a bathroom.
Source: www.rinconesdelatlantico.com

Figure 11: Dry toilet in Mexico.
Source: U. Windblad

Management and operation concept for the dry sanitation solution

The authors developed a theoretical management model based on the idea of a three-monthly collection system for dried faeces and for urine. For this, it is necessary to install storage tanks which have a capacity

[1] pe= person equivalent

significantly higher than the average production. We suggest at least a 50% larger storage than what would be expected to be collected. For urine storage a piping system can be installed that ends in a storage tank close to the collection point. The average urine production is 1.1 l/pe/d (UNESCO IHE, 2008). For a three month collection cycle, a four-person household would need storage for 400 L, and so we planned for a 600 L storage tank. In the case of faeces average production is about 51 l/pe/a. (Vineras, 2002). As the water content of faeces is about 80% (Vineras, 2002) it loses water very quickly and reduces considerably in size and weight. However, some of this loss is offset by the dry material which needs to be added after each use. We estimated the total annual volume to be about 107 L per household per annum or 27 L for each three month cycle. We considered a storage box of 90 L to be necessary in order to guarantee a good air circulation. The box will be in use for three months and than left to rest for three more months. Only after this second period of three months without any new loading will the content be collected.
Transport from the bathroom to the collection point close to the property limit is an aspect which needs further development. In this model, we assume that the transport is done in a container which is very similar to a waste bin on rollers. The user has to transport the container to the collection point just as he or she has to do for solid waste collection.
For collection we intend to use a 10 m³ truck which has a divided tank and two suction devices. A 9.2 m³ compartment would be used to transport the urine, and a 0.8 m³ compartment for the dry faeces. This volume is sufficient to collect from about 23 households. In total, there is a need for four trucks of this kind to cover 10,000 households on a three-month cycle. Detailed calculations are given below in the section about calculating the operation costs. The material is transported to a central treatment facility which consists of a composting place for the faeces and a place for urine storage as recommended for secondary treatment in the WHO guidelines (2006). In order to guarantee a hygienically clean product, the WHO guidelines recommend composting for at least a week with temperatures above 50 C (WHO, 2006 Tab. 4.4). In the model we have allowed for a two month period for composting.
Considering urine, the WHO guidelines recommend storage of six months so that it is safe to be applied on all crops (WHO, 2006 Tab. 4.6). The six month storage period is exceeded in our model by three month storage in individual storage tanks and central storage of four months.
The central treatment centre includes two places for offloading the material and two places for collecting the fertiliser products at the end of the composting and storage period.
The sanitation company will have to introduce an education initiative in order to guarantee the efficient introduction of this new concept. On the economic side, the water tariff has to be strongly progressive in order to discourage people from using waterborne sanitation in an area which is meant to operate on dry sanitation. Controlling the use of water for flushing is one of the most important aspects of successful implementation.

Investment costs for the client in both scenarios

As in every sanitation system, the costs of bathroom implementation have to be paid by the client. The construction of a UDDT bathroom is slightly cheaper than a conventional bathroom. For WS, connection to the sewer is usually charged at about US $150–250. To install a system for urine storage (600 L) and grey water treatment (using a sand filter) a total of US $450 has to be estimated. Onsite storage of urine and treatment of grey water help to cut down costs for the water company. We suggest, therefore, in this model, that the customer gets a payment which leaves him/her paying a net investment equal to that for a WS. The question of whether or not there should be an economic incentive for using the DS model will not be considered in this paper.

Investment costs for sanitation - the waterborne solution

In order to determine the total sewer length, a median width of 10 m per property was assumed with properties on both sides of the street. This leads to a length of 1.25 m/pe, which is a low number and a very pro-WS assumption for the situation in Peru. Costs were taken from various studies of direct costs in Northern Peru. Since we are only interested in the final costs for the sanitation company, we transformed direct costs to final costs (without VAT) by applying a 20% increase to cover indirect costs and profit of the construction company. The costs of digging the sewerage trench are estimated at US $31 per metre. The manholes were estimated at a cost of US $642 with a distance of 80 m between them. The secondary sewer was estimated at US $41 /m. Each connection to the main pipe was calculated at US $192.

For wastewater treatment, two approaches were adopted. In order to come to the lowest possible estimate for WS, it was assumed that wastewater could be treated in a larger wastewater treatment lagoon of more than 200,000 p.e., together with the wastewater from the rest of the city. The design of this plant would be an anaerobic lagoon for pre-treatment, with a manually operated screen, grit removal and facultative and maturation lagoons with a detention time of 20 days (for effective removal of coliforms). For this, the investment would be around US $36 per person. This design was chosen to maximise the benefits of WS in terms of costs; it is still a very common treatment design, but the authors do not consider it a commendable solution. An open anaerobic lagoon always creates a severe smell problem, without mentioning the negative contribution to climate change due to the release of methane. Existing anaerobic lagoons are under review and in Brazil, for instance, more and more are covered with a plastic liner or substituted for by upward-flow anaerobic sludge blanket (UASB) reactors. Today, a sustainable wastewater treatment should not consider anaerobic lagoons without a gas capture system. For these reasons a second approach was also adopted, considering mechanical pre-treatment, with UASB and secondary treatment just for the 40,000 people covered by this system. The estimated costs for this are US $71 a head. These costs are comparable with costs published by the Brazilian National Water Agency in 2001 (ANA, 2001), which gives a cost of US $38 per person for the cheaper solution and a range of US $44 to $61 per person for the second version. The costs presented in ANA (2001) have not been converted to today's prices.
The costs of connection to the sewer, at least one central pumping station and a pressure pipe to reach the treatment plant also have to be considered. The costs of all components, including the pumping station and pressure pipe, are expressed in Table 1. In total, the WC solution has a range of costs from US $574 /household to US $764 /household, or US $143–191 per person.

Item	WS min	WS max
	US $/household	US $/household
Min. Investment for Sanitation	574	764

Table 1: Investment costs of the sanitation part of the WS solutions

Investment costs for sanitation – the dry sanitation solution

In the case of dry sanitation the investment costs had to be developed on a theoretical basis, as there are no examples worldwide.
As mentioned before, a central treatment plant will be installed with a two-month compost storage time. The necessary volume for the storage is 180 m³. The design was carried out with three composting areas 120 m² each, to accommodate a height of 1.5 m for the compost. The composting area costs were calculated for 20 cm of concrete and a 10 cm gravel bed, and allow for the area to be covered. The total comes to US $47,000.
The need to store urine for four months means that a volume of 5,280 m³ will be required (1.1 l/pe/d * 120 days * 40,000 people). Storage would be in 10 LDPE lined storage tanks, each 3 m deep, 10 m wide and 17.6 m long. The containers are totally closed as shown in Figure 12, an example from Bornsjön, Sweden (IHE, 2008).

Figure 12: Urine storage at Bornsjön, Sweden. **(**Source: P. Jensen)

Costings were also made for a filling and draining system. The total sum for urine storage was calculated to be US $107,000.

In order to guarantee rapid loading and unloading, four loading places were included, each of them 10 m long and 4 m wide, with a 200 m² area for manoeuvring. In total, the cost for this comes to US $10,000.

The most significant investment costs are the four suction trucks and a backhoe loader. We adopted prices from Brazil. The truck cannot be compared with normal Hydrojets as there will be no pressure system installed. Instead the truck will be equipped with two suction pumps. The costs were estimated to be US $176,000 for each truck (R$300,000) and US $127,000 for the backhoe loader (R$ 217,000).

Additional installations to complete the system come to US $25,000, including a small operation house, a fence, water and electricity connection, grass in all non traffic areas and a large porch.

In total, the necessary investment for the DS comes to US $1,032,356 or US $103 /household. As pointed out in the investment cost comparison for the consumer, we used an approach in which the service company provides the investment for the urine storage (US $150) and the grey water filter (US $300). Altogether, this makes a total investment of US $553/household (US $103+US $150+US $300).

Investment costs for water provision

The average water loss in Peru is actually 42.4% (SUNASS, 2008). A target has been set to reduce losses from the water distribution systems to 35%. This lower value was used in the current study. Water production in Peru is designed at 1.3 of the medium daily use in order to cover the day with the highest water consumption. Reservoirs are planned to hold at least 30% of the daily consumption.

The necessary water production capacity comes to 12,000 m³/d or 138 L/s for the WS and to 8,000 m³/d or 93 L/s for the DS (see equation 1).

(eq 1) prod. capacity = hab.*(spec. consumption)/(1-water loss)*(factor for highest consumption)

The necessary storage capacity is 3,600 m³ for the WS and 2,400 m³ for the DS (see equation 2).

(eq. 2) Storage capacity = prod. capacity * 30%

For the distribution system, a rough estimate was made. The 50 km secondary distribution system was devised with a primary distribution of various diameters and a 1 km main pipe to the water storage tank.
Table 2 show the specific[2] costs which were used for the comparison. All costs are costs shown for the complete object without VAT.

Item	WS		DS	
	Specific Cost	Unit	Specific Cost	Unit
Water treatment plant	8,990	US $ /(l/s[3])	9,603	US $ /(l/s)
Reservoir	150	US $/ m³	150	US $ /m³
Distribution system (without accessories)	20	US $/m	17	US $ /m

Table 2: Specific costs for the study (costs are drawn from projects in Peru and adopted for the case).

The total length of 51,000 m was estimated at a cost of US $20/m for the WS. The dry solution has a specific cost of US $17/m due to needing smaller diameters. In order to simplify the study the costs for valves and other accessories were considered the same in both solutions and therefore not considered.
Table 3 shows the results. The total investment costs for the water system in the case of the WS come to US $4.6 million or US $464/household whereas the costs for the DS come to US $3.8 million or US $381/household. The DS system therefore has an economic advantage in investment of US $82/household.

Item	WS	DS
	Specific Cost	Specific Cost
Water treatment plant	1,248,608	1,067,051
Reservoir	540,000	360,000
Distribution system (without accessories)	2,849,102	2,386,137
Total	4,637,710	3,813,188
Cost/ household	464	381

Table 3: Total investment for drinking water supply in both scenarios

Theoretical calculation of operational costs for the dry solution

The DS is based on an assumption of a three month collection cycle. Therefore in total it comes to 40,000 visits a year. The calculation of collection costs is the most significant step for the model.
The material which has to be collected is located with a good accessibility at the limit of each property. The emptying truck collects urine and dried faeces at the same time. Typical suction pumps have a flow of 500 l/min. Therefore, the emptying time for the urine storage will be around two minutes. In total, we estimated the working time for each household at five minutes. As one of the authors owns a suction truck for septic tank emptying, the authors do have practical experience in the handling and calculation of such service. We estimate the total necessary time for each household, including moving to the next household, at seven minutes. As this number is very sensitive to errors and in order adopt a conservative approach (pro WS) and in the lack of real specific experience, we used 10 min/household as the basic assumption.
The transport distance we set to 8 km. Considering that a city of 40,000 inhabitants has a total area of about 4–6 km² this distance would correspond to at least 5.5 km distance from the city limits. Average speed was estimated at 40 km/h. Offloading time was estimated at 15 min. The total time per trip is 4.52 h (eq. 3)

(eq.3) total trip time = 23 households* 10 min/household + 16 km/ 40 (km/h)* 60 (to turn hours to minutes) + 15 min

[2] Specific costs are costs which refer to a planning unit i.e. US $/m³ for the construction cost of a reservoir

[3] The water treatment plant costs are calculated as the cost to treat one litre per second. Hence, in this example, a plant that treated 100 litres per second would cost US $899,000. Reservoir costs are measured in US $ per cubic meter of water stored.

In total, the 40,000 collections result in 1,722 trips of 4.52 hours each which comes to 973 (8 hour) days or 44 working months. For the model, we assumed the use of four trucks, allowing an 8% reserve or about 2 days per month for maintenance.

The costs per truck are calculated as presented in Table 4, and the total sum is US $4,588 /month.
This is based on typical salaries for Peru. The petrol is a rough estimation by experience in operation, and maintenance is based on a rate of 3% per year of the investment. The trucks are calculated over a 10 year lifetime.

monthly costs per truck	US $/month
Truck driver	911.76
Worker	705.88
Petrol	1.058.82
Maintenance	441.18
Depreciation	1,470.59
Total	**4,588.24**

Table 4: Monthly costs for transportation of urine and dry faeces per truck

Multiplying this by the number of working months (for four trucks) and dividing by the number of households results in a sum of US $1.74 /household per month for collection of the products.

It was assumed that the central treatment site would require 1.5 persons to supervise reception of the materials. A backhoe loader was included with maintenance costs of 3% per year of investment. The purchase of the backhoe loader is an overestimate. The compost has to be moved once a month, at a quantity of 180 m³ per month, and loaded onto a truck at the rate of 90 m³/month. Table 5 demonstrates the composition of costs, resulting in a US $0.33 cost per /household, per month for treatment and handling of the products at the central treatment plant.

Item	un.	Unit	Total US $ /month
Operator	1.5	Month	1,324
Equipment	3%	year	1,064
Prev. Maintenance	2%	year	331
Energy		gb	88
Guard		gb.	529
Total			3,336
Total / household			0.33

Table 5: Monthly costs for handling urine and dry in the central treatment plant

In addition, costs for education and administration have to be considered. The necessity for sanitation education was based on the experiences of Gounden (2008) in Durban, where about 7% of the users are not using the system properly. We considered one social worker to be needed for education, adding in US $0.10 /household / month.
Administrative costs were estimated at 20% of the product handling costs, coming to US $0.41 /household/month.
Total operation and maintenance costs for the DS solution therefore come to US $2.59 /household/month. In Peru VAT of 19% has to be added. The total cost to the consumer is US $3.08 /household/month.

Cost comparison

Water company costs and investments

Comparing the total investment costs, the WS solution is more expensive than the DS solution (Table 6).
Capitalising this difference with a 30 year period of payment and a 2% interest rate (a very pro WS

assumption), the difference comes to an advantage for the DS solution of US $0.38–1.09 /household/ month for the sanitation company.

Item	WS min	WS 2	DS
	US $ /household	US $ /household	US $ /household
Min. Investment for Sanitation	574	764	553
Investment for water provision	464	464	381
Total	1,038	1,227	485
Difference in favour of DS	103	293	

Table 6: Investment costs of the sanitation part of the WS and DS solutions

Point of view of the consumer

From the point of view of a consumer the situation is as presented in Table 7.

		WS	DS
Water consumption	m³/month	18	12
Water tariff	US $/ m³	0.30	0.30
Wastewater tariff	US $/ m³	0.14	
Monthly bill (water)	US $/month	5.43	3,.62
Monthly bill (sanitation)	US $/month	2.45	3.08
Total bill	US $/month	7.88	6.70
Difference in favour of DS	US $/month		1.18

Table 7: Comparison of the monthly bill for an average household WS and DS solution

The DS solution presents an advantage of US $1.18/month for an average household. It should be considered that this evaluation is done under the current situation in Lima, where water is still very cheap and wastewater is charged at only 45% of the water tariff. This practice will change soon. Since 2008 the water companies are forced (or to put it better, have the possibility) to calculate wastewater charges based on real costs. These costs will certainly be higher than 45% of the water tariff. In Brazil for instance, wastewater tariffs are between 80% and 100% of the water tariff. In Peru, this would result in a difference of at least US $3/month for each household.

The ecologic potential of the dry solution

Irrigation with grey water

The model is orientated towards grey water treatment on site; in future it would be possible for houses to have water for irrigation available. A simple sand filter is a sufficient treatment for grey water (100 l/pe/d) which therefore could be reused in the property. The basic calculation for irrigation is normally a 5 mm dose per day in the dry coastal areas of Peru, at least in the summer time (5 l/m²/d) That means, that the grey water from one family (300-500 l/d) is sufficient for a constant irrigation of 60-100 m² of green area. The treatment filter will itself need an area of 3-4 m². The water can be used for green areas around the houses, gardens with vegetables, fruits, flowers or also for parks. Irrigation with drinking-quality water, as practised in many parks of Peru, uses water which could be used to supply more families with clean drinking water.

Saving of freshwater resources

With the fresh water saved by 40,000 people (3.076 m³/d) it would be possible to irrigate a desert area of at least 61 hectares for agriculture (5 mm/m²/d; calculated for high water consumption plants). In total, a desert area of 141 hectares could be irrigated when the drinking water consumption of 40,000 people is reduced by one third and when all grey water is treated and reused for irrigation purposes.

Substitution of fertiliser

Urine is characterised by having a high quantity of nitrogen, phosphorus and potassium, the most important nutrients for plant growth. The urine passed by one person in a year is equivalent to 4 kg of Nitrogen, 0.4 kg of Phosphorus and 1 kg of Potassium. In the case of urine separation these nutrients can be used more or less directly as fertiliser (UNESCO IHE, 2008). The urine from 40,000 people in one year contains 160 tonnes of nitrogen, 16 tonnes of phosphorus and 40 tonnes of potassium.

The most important nutrient for the Peruvian agriculture is nitrogen and in 2008 the prices for synthetic urea raced up by 50%, due to high energy prices. Synthetic urea costs US $600 per tonne (El Comercio, 2008), which is too expensive for small farmers. Synthetic urea has a content of 46% N; therefore the urine of 40,000 people would replace 348 tonnes of synthetic urea, which has an economic value of US $208,700 or US $21 per year for a four person family.

Cultivation of corn, potato, wheat or cotton normally require between 100-200 kg N/ha during growing season. The urine from 40,000 people would therefore be sufficient for nitrogen fertilisation of at least 800-1,600 ha of agricultural land.

From an ecologic point of view the use of urine instead of synthetic urea reduces CO_2 output, because it avoids the use of natural fuels for urea production. Unlike synthetic urea, urine also contains potassium and phosphorus compounds, both normally used as additional fertilisers in the form of commercial products with 10-50% P_2O_5 and 30-60% KCI or K_2SO_4, which causes additional costs for the farmers. The main problem is the limit on natural resources for phosphorus, which are predicted to run out in about 50 to100 years (UNESCO IHE, 2008)

The use of urine as a fertiliser for private gardens would result in higher economic benefits according to calculations carried out for a UDDT application (Jönssson et al., 2005). Repeating these calculations for Peru where a common 30:10:10 NPK fertiliser costs about US $1.50/kg, and 1 kg is recommended for a 15 m² application (0.02 kgN/m²), suggests that the urine from a four person family has a theoretical value of US $80 per year. However, two points have to be considered: a family has enough urine to fertilise 800 m² or more but the normal size of a property is 250 m² with a maximum of 100 m² green area, and the NPK fertiliser for 100 m² costs only about US $10 per year. It is obvious that this approach cannot be used for large scale applications in urban regions in Peru.

The way forward

In the theoretical example we have presented, which still needs more detail, dry sanitation has proven itself as the better economic and ecologic solution. Considering that the authors have always tried to make assumptions that favoured WS, dry sanitation has to be seen as *the* measure to adapt to climate change in desert areas.

DS also offers much more flexibility in construction, as there is no need for all the investment to be implemented immediately. DS offers a step by step approach, growing exactly at the speed to match need, as most of the investment and operational costs are directly related to the number of households demanding the service. In the opinion of the authors, this is the most important aspect of the dry sanitation solution. More people can be reached in a shorter period of time by applying DS instead of WS.

If this is so, why don't we already have a much greater number of DS solutions?

We need practical examples! It is nice to have a theoretical model and there are proven solutions for every aspect, but there is no complete application. There is no danger for a sanitation company that the model would not work. But we need real-life examples to overcome the problems that any new approach will always meet in practical implementation. This is necessary in order to be able to further develop the model to full mass application.

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