SANIRESCH

Research Project

SanitaryRecycling Eschborn SANIRESCH

English Project Factsheets

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Research Project SanitaryRecycling Eschborn (SANIRESCH)
Project component: Sanitary and In-house Installations

1. Background

The SANIRESCH project was designed to demonstrate and investigate the possibilities of a source-oriented wastewater separation and its reuse. For this purpose 50 RoeVac® NoMix toilets, urine-diversion flush toilets, and 23 waterless urinals of Keramag were installed at GIZ headquarters in Eschborn in 2007. At this time the urine-diversion toilets of Roediger Vacuum were five years on the market but only in small numbers. Therefore there was only very limited data available concerning their operational performance. Within this project the operation and maintenance of this toilet type was investigated and the design was further adjusted.

2. Material and methods

The operational performances of the NoMix toilets and waterless urinals were monitored regularly in a logbook. Monthly routine controls of the toilets and urinals have been executed as well as biannually preventive maintenance for the toilets. The results have been recorded in the log book to illustrate the operating conditions and evaluation process. Logbook entries for toilets were taken in the period from August 2010 till April 2012 while urinals were recorded from October 2009 till to date. The evaluation helps to draw conclusions about quality improvements, the liability of the different components as well as the quality of maintenance services.

The analysis for the NoMix toilets was specifically focused at the aspects of number and nature of disorders, performance and service life of the integrated urine valves and other spare parts. The urinal testing was focused on the cleanliness as well as on their functionality by a monthly routine check. After a time period of 6 to 12 months (depending on the number of uses) the rubber tube seals get porous, tend to stick together or are not closing anymore. This malfunction leads either to stagnant urine in the toilets or smells leaving the urine piping system.

However, smell issues were not only reported in relation to the urinals. Also toilet malfunctions provoked odour nuisances. Due to urine scale deposits the urine diverting valves integrated into the NoMix toilets stop closing effectively and again smells from the urine piping system can enter the toilet room. To prevent the deposition of urine scale monthly cleaning routines were established. Citric acid of 10% concentration was filled into the urine valves of the NoMix toilets and washed out afterwards to prevent damage of the valves through the acid. The rubber tube seals of the urinals are checked and exchanged weekly. If the rubber tube seal is inoperative it is removed instantly or washed under running water using a brush.

3. Results and discussion

3.1 NoMix toilets

The interior of the NoMix toilets allows the separation of urine and faeces. A crucial component enabling this separation is a urine diverting valve. After several months of operation it became obvious that the valve is susceptible to failures due to depositions of urine scale. As a result a total of 221 disorders were recorded in the report period of 20 months. The most sensitive spare part exchanged most often was the bowden cable, followed by the urine valve itself (for details see Figure 1).

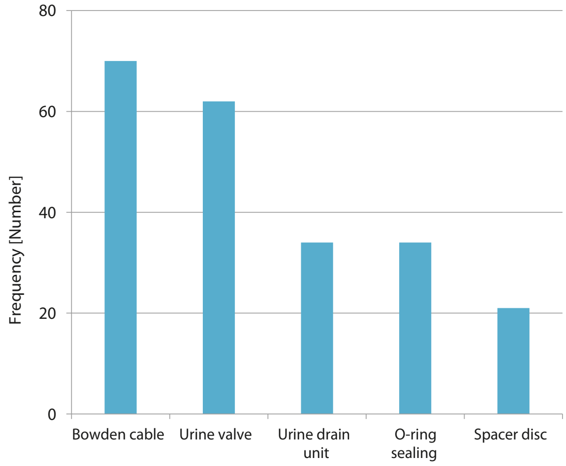

Figure 1: Exchange rate of NoMix toilet's spare parts within the project.

During the operation time several optimisations of the technical components of the NoMix toilets were conducted and applied in the existing system.

- The bowden cable that opens and closes the urine valve was extended by 20 mm.
- The holder unit of the bowden cable was re-designed. Both interventions eased the process of joining and fixation of the bowden cable.
- The edges within the urine valve were smoothened to improve the flow velocity and prevent the precipitation of urine scale.
- The sealings of the urine drainpipe unit were optimised with two O-rings to reduce the number of leakages between the inserted valve and the porcelain.

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Furthermore, the flushing performance of the NoMix toilets was not as efficient as desired. Therefore double or multiple flushings were required leading to increased water consumption. However, the solution of this problem would have required substantial modifications and re-design of the toilet bowls and could not be achieved within this project. The logbook data was used to calculate the service life of the different components. The technical improvements mentioned above were not regarded in this calculation. The service life of a urine valve is 495 days. For the other components the calculations led to a service life of 429 days for bowden cables, 776 days for wash pipe connections, 759 days for rubber rings and 945 days for distance washers.

3.2 Waterless urinals

The user's evaluation of the cleanliness of the urinals shows that they have a slightly worse impression towards conventional urinals (for details see also factsheet „Acceptance"). That made it necessary to focus on the cleaning routines performed by the cleaning personal, especially to guarantee a clean outlet (see Figure 2). It could be shown that instructing the cleaning staff in terms of the cleaning routines has a major effect on the successful operation. As already mentioned before the seals used in the urinals are more prone to malfunctions than regular urine siphons and need constant cleaning. In the beginning of the project, the maintenance staff took the seals out and while cleaning them, the access to the piping system remained open. This caused strong odour nuisances in the toilet room and the staff was very much hesitant to perform the cleaning procedure.

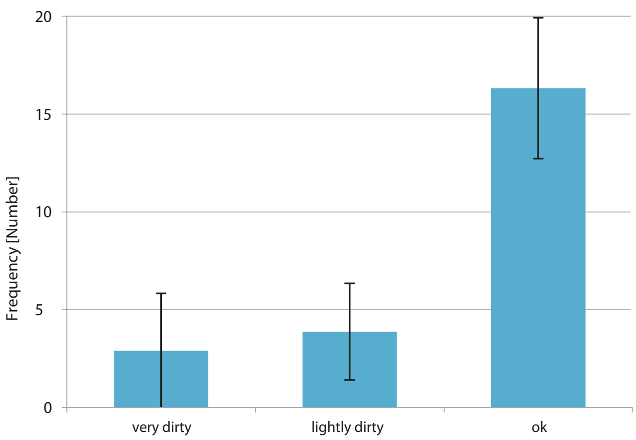


Figure 2: Overview of the level of cleanliness of the applied membrane seals.

4. Conclusion and outlook

With the end of the SANIRESCH project Roediger Vacuum will terminate the commercial marketing of the NoMix toilets.

This decision was inevitable due to several reasons:

- The design of the toilet bowl is complex which leads to high scrap rates during production. NoMix toilets are therefore unattractive for sanitation porcelain producers and no companies were found as production partners.
- The toilets require a high level of maintenance.
- Market segments that would allow higher maintenance efforts like public sanitation facilities will very likely result in a high misuse rate leading to a low efficiency in terms of urine diversion.

Roediger Vacuum will concentrate on the further development of the RoeVac® Vacuum - Sanitation System that also enables an efficient wastewater separation in black- and greywater in a larger scale. From the separated blackwater all valuable nutrients can be recovered for agricultural use additionally producing biogas.

To prevent user's refusal to waterless urinals it is very important to have a strict cleaning routine with short cleaning intervals adapted to the number of uses per day. Also the cleaning staff has to be instructed regarding the exact cleaning routines and has to be supplied with the necessary equipment. Since the waterless urinals can be operated cost efficient and are easy to install, especially buildings with high frequencies like roadhouses, airports or train stations are equipped with this technique.

5. Acknowledgements

This research was realised within the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry for Education and Research), fund No. 02WD0951 and 47. The authors thank the BMBF for the financial support. The authors thank also Christoph Stein, Matthias Hartmann, Katharina Löw, Amel Saadoun, Fanny Kilian and Tobias Ochs for their major support in the monthly and biannual controls.

Authors: Henning Sälzer, Tobias Ochs, Christian Rüster

Responsible partner: Roediger Vacuum GmbH
Kinzigheimer Weg 104 – 106
63450 Hanau, Germany

Publisher: Coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

SANIRESCH

Research Project SanitaryRecycling Eschborn (SANIRESCH)

Project component: Plant Technology

1. Introduction

The objective of the research project SANIRESCH is the treatment and utilisation of the different wastewater flows which are generated in the main building of GIZ in Eschborn: yellow-, brown-, greywater. The greywater and brownwater flows are treated in a MBR (membrane bioreactor) process, a combination of biological wastewater treatment and membrane ultrafiltration. A MAP (Magnesium-Ammonium-Phosphate) precipitation reactor is used to treat the urine. The main task of HUBER SE within this project has been the installation and process engineering optimisation of the complete technical equipment.

2. Wastewater treatment concept and equipment

During the comprehensive renovation of one building of the GIZ headquarters in Eschborn, the middle part of this building was equipped with separate pipe systems for yellow-, brown- and greywater. The wastewater flows are discharged via three lines which lead into a technical installation room on the basement floor of the building. Within the SANIRESCH project HUBER SE installed the technical plants for the recovery of nutrients (phosphorus and nitrogen) from yellowwater and the production of process water from grey- and brownwater (Figure 1):

- MAP precipitation reactor for yellowwater treatment.
- Collection tank with integrated mechanical pre-treatment system and membrane bioreactor for brownwater treatment.
- Collection tank with integrated mesh screen, membrane bioreactor (MBR) and process water storage tank for greywater treatment.

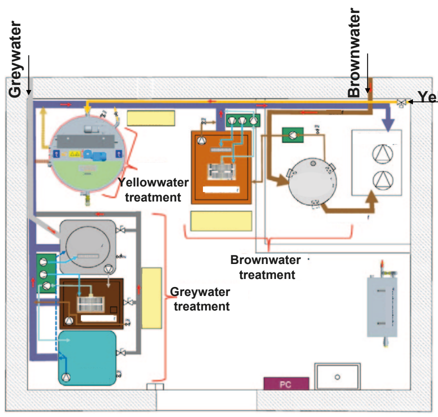
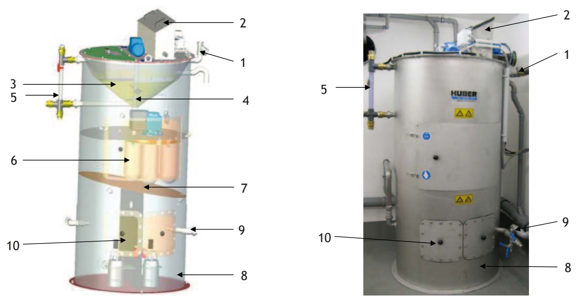


Figure 1: Potential hotspots for the implementation of all three analysed technologies.

2.1 Yellowwater treatment

The yellowwater is treated with a chemical-physical process in a MAP precipitation reactor which is specifically designed for the GIZ project requirements. By addition of powdery magnesium oxide (MgO) to undiluted or slightly diluted urine magnesium ammonium phosphate (MAP) in solid form is generated in the MAP precipitation process. This MAP is a high quality fertiliser which can be used in agriculture. The reactor consists of a precipitation tank with stirrer, a dosing system using bags and a filtration unit with filter bags (Figure 2 and Table 1).



1 Filler, 2 Dosing unit, 3 Precipitation tank (trough-shaped), 4 Stirrer, 5 Level probe, 6 Filter bag, 7 Collecting tray for process water, 8 Chamber for process water, 9 Outlet, 10 Inspection opening

Figure 2: HUBER MAP precipitation reactor installed in the technical installation room.

Table 1: Characteristic data of the MAP precipitation reactor.

Operation mode	Batch mode
Maximum amount of urine per cycle	50 l
Cycle duration (filling, stirring, sedimentation, draining supernatant urine, draining the urine enriched with MAP)	adjustable e.g. 135 min with 10 cycles a day

2.2 Brownwater treatment

A MBR plant with upstream mechanical pre-treatment system is used to treat the brownwater (Table 2). A small horizontal micro strainer with a 3 mm perforated plate retains coarse material and toilet paper. If required, the screenings can be collected separately to be composted. The pre-screened brownwater is treated in a compact MBR with an integrated ultrafiltration unit to produce process water. Due to the high organics load (faeces) more aeration tank volume is required than in municipal MBR applications.

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Table 2: Characteristic data of the brownwater treatment system.

Pre-treatment	Perforation	3 mm diameter
Membrane	Pore size (nominal)	38 nm
	Membrane material	PES (polyether sulphone)
	Membrane surface	3.5 m^2
Volume	Collection tank	max. 400 l
	MBR tank	max. 700 l

2.3 Greywater treatment

The greywater from kitchens, hand wash basins and wash water sinks is treated with a mechanical pre-treatment system combined with the membrane bioreactor (Table 3). The mechanical pre-treatment system is a 3 mm mesh screen which retains disturbing coarse material and hair. The aerated collection tank serves as a buffer tank for the daily generated greywater volumes. It is in the compact MBR stage where the biological treatment of the pre-screened greywater takes place, followed by membrane ultrafiltration. The process water is stored and used to clean the mechanical pre-treatment system.

Table 3: Characteristic data of the greywater treatment system.

Pre-treatment	Mesh screen	3 mm
Membrane	Pore size (nominal)	38 nm
	Membrane material	PES (polyether sulphone)
	Membrane surface	3.5 m^2
Volume	Receiver tank	max. 480 l
	MBR tank	max. 500 l
	Process water storage tank	max. 480 l

3. Project specific requirements

A special challenge in this project has been the integration of the technical equipment into the existing building structure and remote control of the decentralised plants.

3.1 Equipment integration into the existing building structure

Only a small room (21 m^2) was most suitable to install the complete technical plants for the treatment of the individual wastewater flows. It was therefore a special challenge to integrate the equipment, including all associated pipelines, into the existing building structure. We planned in a way to ensure that access to the plants is possible at any time to carry out maintenance work, take samples or show the plants to visitors. Furthermore, all plant components are totally encased to avoid undesired odour annoyance during operation. All relevant technical DIN standards were taken into account when the installation work in the cellar room was carried out. We used preferably modular plant components which we adapted to suit the specific conditions in this office building in terms of size and design.

3.2 Control of operations including remote data transmission

Under this project the Technical University Mittelhessen (THM) was responsible for the operation of the complete technical installations. To ensure remote control of the automated plant operation the control systems of all plants are equipped with remote data transmission including fault reporting via SMS. This transmission technology provides access to all operating data of the decentralised plants from an external control station to evaluate their operating states. Regular data evaluation allows for the targeted control of equipment operation and early detection of certain trends. Undesired standstill times and extensive service work can be reduced to a minimum.

4. Summary

Under the SANIRESCH project the complete technical plant equipment for the treatment of yellow-, grey- and brownwater has successfully been integrated into the existing structure of the GIZ building in Eschborn. Due to the modular design of the plant components a high level of functionality could be achieved despite scarce space on site. To ensure remote equipment control the decentralised plants are equipped with remote data transmission including fault reporting via SMS. This minimises undesired standstill times and extensive service work. With the installation of these plants for the separate treatment of individual wastewater flows in the GIZ building HUBER SE has successfully contributed to establishing NASS (New Alternative Sanitation Systems) in existing buildings. Under this research project the basis has been laid for closing decentralised water and material loops in urban areas, with an office building as example. This demo project can constitute a new standard for future applications in so-called 'green buildings'.

5. Acknowledgements

HUBER SW would like to use this opportunity to thank the German Federal Ministry of Education and Research (BMBF) for supporting the SANIRESCH research project (reference no. 02WD0952), and all other parties involved in the project for their good cooperation.

Authors: Stefania Paris, Martin Feicht, Celine Schlapp, Thomas Netter

Responsible partner: HUBER SE
Industriepark Erasbach A1
92334 Berching, Germany

Publisher: Coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

Research Project SanitaryRecycling Eschborn (SANIRESCH)
Project component: Operation and Monitoring

1. Background

This project component of the research project SanitaryRecyclingEschborn (SANIRESCH) was responsible for the operation and monitoring as well as the optimisation of the three plants. This included monitoring with remote control, error control, regular inspections, as well as the maintenance of the equipment. Furthermore wastewater parameters of yellow-, brown- and greywater were analysed, data was evaluated and consumables for continuous operation were supplied.
The optimisation included improvement of the plant operations, the settings of the chemical process and the associated basic parameters and procedures.

2. Approach

2.1 Structure and functioning of the urine precipitation plant

Urine, collected by waterless urinals and separating toilets, is first saved in one of four collecting tanks, with a respective capacity of 2 m^3. By hydrolysis of urea (Equation 1), the pH (> pH 9) and ammonium concentration increase.

$$CH_4N_2O + 2\ H_2O \rightarrow NH_4^+ + HCO_3^- + NH_3 \quad \text{Equation 1}$$

In the precipitation plant developed by HUBER SE, 30-50 l urine can be treated per precipitation cycle. Low-cost technical magnesium oxide, with a ß-factor of 1.5, is used as precipitant. After the addition of magnesium oxide by a dosing unit, a stirring period with alternating stirring and pause intervals, each 30 s for 3 min., follows. The dosage of magnesium oxide causes the following precipitation reaction (equation 2):

$$Mg^{2+} + NH^4+ + PO_4^{3-} + 6\ H_2O \rightarrow MgNH_4PO_4 \bullet 6\ H^2O\downarrow \quad \text{Equation 2}$$

The sedimentation process requires 90 min. The generated MAP (MgNH4PO4 • 6 H2O, struvite) is collected in the cone of the funnel-shaped precipitation area. After sedimentation the treated urine is discharged into polypropylene filters, with a pore size of 10 µm (see Figure 1).

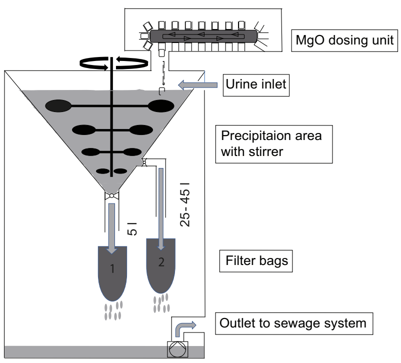

Figure 1: Schematic drawing of the MAP precipitation reactor.

2.2 Mode of operation of the membrane bioreactors

The MBRs were usually operated with a constant low sludge loading of 0.1 kg COD kg^{-1} TS d^{-1}. The necessary permeate (filtrate) volume was calculated based on the measured concentration of COD in the inlet and the biomass concentration in the activate sludge tank. By this mode of operation the trans-membrane pressure varied between 45 and 75 mbar for the greywater plant and between 37 and 68 mbar for the brownwater plant. Due to the highly fluctuating characteristics of the influents it was intended to create a trouble-free and stable operation.

Usually membrane bioreactors operate with biomass concentrations (TS levels) of approximately 12 g l^{-1}. For reasons of operational stability, both MBR were operated with a constant TS of 4 g l^{-1} (greywater) and 8 g l^{-1} (brownwater).

3. Results and discussion

3.1 Mass balance of the precipitation reaction

The mass balance of one storage tank (2000 l) shows that 97% of dissolved phosphate can be recovered by MAP precipitation with analytical MgO (see Figure 2) (Röhricht et al., 2012).

However by using low-cost, technical MgO the yield decreases to approximately 65%. Technical magnesium oxide was used for regular operation of the precipitation reactor for cost reasons. The price for 1 kg of analytical MgO is approx. 500 Euro, whereas technical MgO is available for only 20 Euro.

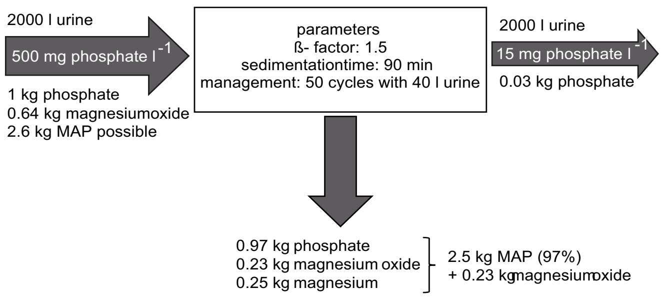

Figure 2: MAP mass balance of a storage tank (2000 l), precipitation with analytic MgO.

In the present project 0.7 to 1.3 g MAP could be recovered per litre treated urine with technical MgO as precipitant.

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3.2 Analytic and process parameters of the membrane bioreactors

The nutrient ratio C:N:P of the greywater was usually 100:2:1, the ratio of brownwater was 100:9:1. The composition of the wastewater flows largely correspond to those who are described in literature. The greywater MBR reached a COD purification efficiency of 96%, the brownwater MBR of 97%. Chemical parameters of the inlet flows and permeates of the grey- and brownwater membrane bioreactors are compared in Table 1.

Table 1: Chemical parameters of the inlet flows and permeates of the grey- and brownwater membrane bioreactors (greywater: average of 50 samples; brownwater of 45 samples)

			Greywater		Brownwater	
			inlet	permeate	inlet	permeate
COD	[mg l^{-1}]	ø	647	28.5	803	23.0
		min	329	17.2	238	13.8
		max	1455	39.5	1439	39.8
TN_b	[mg l^{-1}]	ø	15.6	12.5	69.8	72.9
		min	5.36	5.4	13.4	24.9
		max	35.8	25.7	190	170
P_t	[mg l^{-1}]	ø	21.5	15.6	24.2	22.0
		min	2.84	3.4	6.93	3.82
		max	60.4	29.2	48.5	59.4

Membrane bioreactors are usually operated with flux values of 20 - 30 l m^{-2} h. The MBRs in this project were operated with an average flux of 6.6 l m^{-2} h^{-1} for greywater and 10 l m^{-2} h^{-1} for brownwater. The low loading of the membrane was due to the need for operating stability. Occasionally there was also a shortage of greywater. The average throughput of the greywater MBR was 324 l d^{-1}, corresponding to a retention time of 37 h. The average throughput of the brownwater MBR was 542 l d^{-1}, corresponding to a retention time of 36 h.

3.3 Classification of the permeate into quality criteria

The reuse of water is the main motivation for grey- and brownwater treatment. The specific hygiene quality requirements depend on the intended use. Usually the BOD_5 concentration (storage capacity), turbidity (aesthetic concerns) and the microbiological load (health risks) are considered as relevant quality parameters (for details see also factsheet "Quality of products").

Table 2: Comparison of values and quality requirements for toilet flushing water, irrigation water and drinking water with the average values of the permeates of grey- and brownwater

	fbr H 201	DIN 19650	EU drinking water directive	grey-water[3]	brown-water[3]
COD [mg l^{-1}]	-	< 60	-	28.5	23.0
BOD_7 [mg l^{-1}]	< 5	< 10(BSB_5)	-	1.5	1.6
O_2 conc. [mg l^{-1}]	> 50%	-	> 5	8.8	8.3
Turbidity [NTU]	-	-	< 1	0.4	0.5
Total coliforme	< 100/ml	-	0/100 ml	1.1/ ml	2/ml
E.coli	< 10/ml[1]	0-2000/ 100 ml[2]	0/100 ml	0.4/ ml	0/ml

[1] applies to faecal coliforms [2] depending on qualification level [3] average values (for details see also Table 1)

According to fbr note sheet 201 both permeates comply with the requirements for toilet flushing water. Furthermore the permeates are useable as irrigation water. According to DIN 19650 four qualification levels are distinguished. Although both permeates do not comply to level 1, they can be used for the irrigation of sport facilities and public parks as well as for products not intended for human consumption, fruits, vegetables for preservation and vegetables until two weeks before harvest (DIN 19650).

4. Conclusion

The project demonstrated that a decentralised and separated wastewater treatment in an office building with limited space available is technically feasible. The phosphorus precipitation from human urine is a promising way to recover phosphorus. It has been shown that the process is possible on an industrial scale and continuous operation. The water quality of purified brown- and greywater allows the reuse as toilet flushing and irrigation water.

5. Major references

Röhricht, M., Hartmann, M., Heynemann, J., Winker, M., Paris, S.(2012): Phosphate recovery from urine by MAP-precipitation, book of Abstracts on Ecotechnologies for Wastewater Treatment 2012, IWA International Conference, Santiago de Compostela, June 2012.

6. Acknowledgements

This research was realised within the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry for Education and Research), fund No. 02WD0950. The authors thank the BMBF for the financial support.

Authors: Johanna Heynemann, Markus Röhricht

Responsible partner: University of Applied Sciences Mittelhessen (THM)
Wiesenstrasse 14
35390 Giessen, Germany

Publisher: Coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

SANIRESCH

Research Project SanitaryRecycling Eschborn (SANIRESCH)
Project component: Quality of the Products / Storage of Urine

1. Background

Though the agricultural use of urine and faecal matter as fertiliser has a long tradition, the knowledge about their infectious potential, the introduction of water flushed toilets and modern wastewater treatment relocated nutrients and pathogens to treatment plants and made urine and faeces unattractive for direct use. Additionally, the amount of excreted pharmaceuticals in human urine and faeces excludes them from direct use in Germany and many other countries today. The precipitation of nutrients from urine (nitrogen and phosphorus) as struvite makes it an interesting source for phosphorus and nitrogen recovery. Many research projects dealing with pharmaceuticals in urine and faeces under environmental aspects have been undertaken.

Separating the different wastewater streams into brown-, yellow- and greywater is an approved method for water reuse. The utilisation of the different treated flows and products is a well appreciated source for nutrients as well as for water for toilet flushing or irrigation for example. The aim of this subproject was to analyse the behaviour of pharmaceuticals and bacteria during storage, precipitation and treatment in all three wastewater streams and in the precipitated product struvite.

2. Practical approach

Urine was separately collected and stored and the amount of pharmaceuticals analysed prior to the further experiments. Seven different pharmaceuticals have been detected in the original urine at GIZ and were included in different experiments. One active agent (chloroquine) was added under the aspect of the application of struvite as fertiliser in tropical regions where chloroquine is a well known and cheap medicament against malaria though chloroquine resistances exist.

Prior to direct use the storage of urine for six months is recommended by the World Health Organisation (WHO, 2006) to reduce the number of infectious bacteria. In the framework of the project urine was stored for six months in a dark place at 20°C adding 100 µg l^{-1} of different active agents and adjusting pH to 3, 6.5, 8.5, 9.5 and 11 respectively. The elimination of the added pharmaceuticals was measured via liquid chromatography and mass spectrometric detection.

Before the use of struvite as fertiliser the product must be dried and proof its applicability for usage as fertiliser concerning the content of nutrients and hazardous substances. Experiments were carried out drying struvite of the urine precipitation plant of GIZ at different temperatures and measuring the content of medicaments and some chemical elements.

Analyses of the influent and effluent of all pilot plants, MAP (Magnesium-Ammonium-Phosphate = struvite) precipitation reactor as well as membrane bioreactors (MBR) for grey- and brownwater treatment were undertaken to detect the concentration of pharmaceuticals and surface active agents, the hygienic quality as well as the toxic effect of the greywater effluent on *Daphnia magna*.

3. Results and discussion

The storage experiments with spiked urine at different pH-values proved that the adjustment of urine to a certain pH-value has no effect on all the tested agents of the different pharmaceuticals that might be detected in the urine of a variety of different people. A high elimination rate of more than 90% resulted from the effect of a very low or very high pH-value on some chemicals (pH 3: diclofenac, pH11: sulfadimidine). Storing the urine for six months without any pH adaptation showed an elimination effect of 60 to 80% for carbamazepine, chloroquine and sulfadimidine only (see Figure 1).

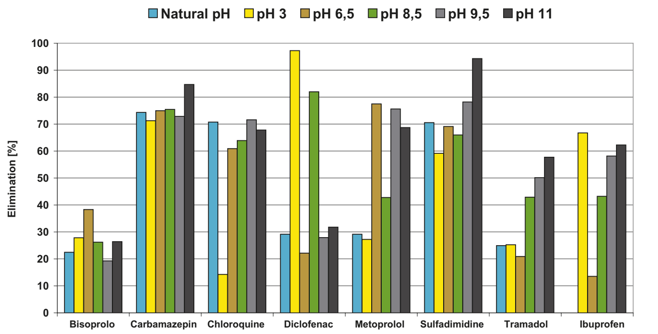

Figure 1: Elimination rate of the pharmaceuticals during storage at different pH-values.

After precipitation of struvite the fertilizer must be dried to allow a safe and hygienic application in agriculture. Comparing the concentration of the struvite ingredients nitrogen (N),

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phosphorus (P) and magnesium (Mg) after drying at 30, 50, 70 and 105°C showed a significant loss of N at 50°C of about 50% while at lower temperatures the molar ratio of N, P and Mg stays stable. The concentration of the tested pharmaceuticals in struvite produced from urine collected in an office building is below the limit of quantification of 1 μg l^{-1} of the applied analytical method (LC-MS) after washing the struvite in a saturated struvite solution and the dried product is free of faecal bacteria as well. The bacteria reduction results from the drying process as the dehydrating effect of the dried mineral on the bacteria causes a disinfection of the fertiliser concerning the analysed bacterial species E. coli and intestinal enterococci.

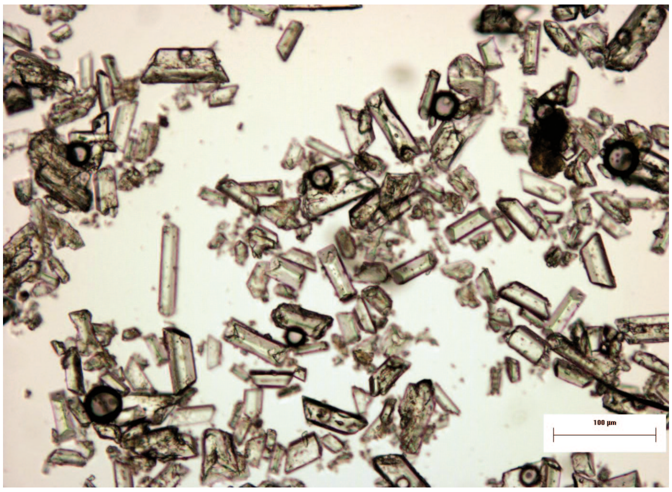

Figure 2: Struvite crystals (indication of size: 100 μm).

In the framework of the project greywater and blackwater were treated biologically in membrane bioreactors. Prior to reuse the effluent of the treatment plants must at least show a suitable microbiological quality falling below the limits of the EU bathing water directive indicating 200 cfu 100 ml^{-1} for intestinal enterococci and 500 cfu 100 ml^{-1} for E. Coli in bathing water of excellent quality. All results of the greywater treatment plant hit these requirements in the effluent of the MBR as well as in the storage tank for the cleaned water. Due to a re-infection of the effluent tube from environmental effects and as to difficulties in sampling the blackwater effluent showed varying results. Normally the effluent of a blackwater treatment plant with membranes hits the hygienic requirements of the bathing directive as well and may be reused in a similar way like treated greywater.

Medicaments could only be detected in the effluent of the blackwater treatment plant. One sampling showed bisoprolol in the influent and in the effluent of the treatment plant when the bisoprolol concentration was very high in a parallel urine sample as well. Ibuprofen was detected twice in the effluent of the blackwater treatment plant. The concentration of all other analysed pharmaceuticals was below the limit of quantification of 1 μg l^{-1}. As only hand wash basins, dishwashers and no showers were connected to the greywater treatment plant just surfactants and caffeine were detected here. Caffeine was completely degraded in the treatment plant and the concentration of tensides was reduced by 90% during the treatment process. As many different cleaning agents are used in the office building it was not possible to specify and identify the sources of the different chromatographic peaks.

The effluents of the greywater as well as of the blackwater treatment plant had no inhibiting effect on *Daphnia magna* (test procedure: DIN 38412 Part 30).

4. Outlook

Separation of different wastewater streams is a reasonable and sustainable approach to save water and to protect natural resources by recycling phosphorus and nitrogen. The technology of precipitation of natural urine leads to a product that is free of medicaments and has no harmful effects when used as fertilizer. The treatment of the other wastewater streams greywater and blackwater via membrane technology generates an effluent of water that forms an interesting alternative for usage as service water for toilet flushing, garden watering, industrial use and even the washing of laundry. Prior to use in nature all treatment products that have been received should pass the relevant toxicity tests in future to avoid acute and chronic toxicity effects on the food chain.

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6. Acknowledgements

All investigations were realised in the framework of the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry of Education and Reseaech), fund No. 02WD0949.

Authors: Bettina Schürmann, David Montag

Responsible partner: Institute for Environmental Engineering
RWTH Aachen University
Mies-van-der-Rohe-Str. 1
52074 Aachen, Germany

Publisher: Coordination by Deutsche Gesellschaft
für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

SANIRESCH

Research Project SanitaryRecycling Eschborn (SANIRESCH)
Project component: Acceptance

1. Background

Acceptance identifies the attitude of a larger group of people towards a special technology without giving any special reasons for their opinion and behavior. Social acceptance of a new technology and its impact on society is a precondition for its successful and widespread implementation. Therefore, the SANIRESCH project included a user acceptance analysis. As the NoMix toilets have been installed in a part of the building I of GIZ, the employees working there have been interviewed about their experiences with and opinion of the toilets. This way, it should become clear whether the users approve the idea of recycling urine and conserving water or not and show if the practical realisation succeeds in satisfying the user's expectations.

In a further study, potential users of the created fertiliser products were questioned. Farmers were asked regarding their attitudes towards the new recycling products - yellowwater and MAP – and if they were interested in applying those to their fields. Furthermore, consumers had to give their opinion on buying, eating and using agricultural products fertilised with these products.

2. Conducted surveys

About 400 employees have been asked to participate in the anonymous opinion survey for three times to analyse the development of acceptance during the project (with a regressive number of answers: 127, 67, 36 respectively). The questionnaires included a fixed part of questions for all participants, gender-specific questions and additionally variable ones according to the recent project developments.

For the farmers´ study, 400 questionnaires were sent to all registered farmers and gardeners of the Landwirtschaftskammer in North-Rhine-Westfalia (NRW). For the consumer study, 500 consumers, randomly distributed in NRW received questionnaires. Of those, 100 returned questionnaires could be evaluated.

3. Results and discussion

3.1 Sanitary system

More females than males participanted in the GIZ survey. The results of all three surveys show that the waterless urinals are well accepted. Regarding the utilisation and cleanliness, men rated the waterless urinals as *comparable* to conventional urinals, while the smell of waterless urinals was rated as *gradually worse*.

Most people confronted with the NoMix toilets and not involved into the project before have the tendency to judge the NoMix toilets *worse* than others. During the project, the users did not only get a better knowledge of the technique but also indicated that it is necessary to get detailed information about this new toilet type and its usage. Within the third survey, all participants were able to answer questions concerning the usage of the NoMix toilets correctly. The users have a strong tendency to favour conventional toilets over NoMix toilets. Less than one quarter of all participants of the third survey indicated to prefer the NoMix toilets or not to have any preference.

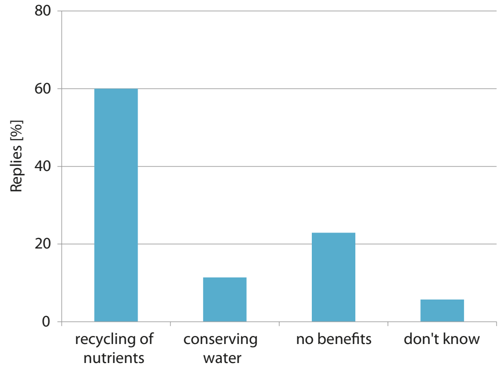

Figure 1: "In your opinion, what is the key benefit of the NoMix toilet?".

A reason for this may be seen in the technical and hygienic problems that occur when using the NoMix toilets. About 70% of all users indicated that they sometimes cannot flush the toilet as usual. More than 20% of the participants of the third survey had already experienced blocked toilets. Concerning hygienic problems, especially women indicated to be confronted with a dirty toilet bowl or seat as well as annoyance caused by bad smell when using the NoMix toilets. Most users judged the flush as not powerful enough. This is why about 65% of all users activate the ordinary flush at least two times for every usage. This may be a reason why many users do not consider the conservation of water as a benefit of the NoMix toilets. More than 30% of the participants rated the usage as *much worse* in comparison to conventional toilets. About 70% of the users think that the cleanness is *worse* or *much worse* than of conventional toilets.

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The results show that the problem of dirtiness within the NoMix toilets is not the consequence of a lack of cleaning through the cleaning staff but of careless toilet use by the users themselves. As can be seen in Figure 1, the users' opinion about the NoMix toilet is divided. One part accepts it and thinks it is a good idea to conserve water and help the environment whereas the other part refuses the idea and judges it as a step backwards in development. Asked about the key benefit of NoMix toilets 60% answered *recycling of nutrients*. The users' interest in using the NoMix toilet at home is not high, but most people would accept inedible as well as edible products produced with reclaimed nutrients.

3.2 Fertiliser products

Anonymous answers of 27% of farmers could be evaluated. Of those, 95% were male, most of them between 40-60 years old (73%). Their farm sizes usually ranged between 50-100 ha (43%) and 100-200 ha (25%). The third group with 15% owning 0-10 ha consisted mainly of gardeners. Besides a number of background questions on farm management, environment and preferences, farmers gave their attitude regarding two products: a liquid fertiliser (urine from a sanitary system) and a composed solid powder fertiliser based on urine. Farmers and gardeners were aware of the fact that urine contains quite a lot of nutrients (62% yes to 10% no, 28% did not answer the question).

Most of them were quite open towards a urine based fertiliser. Two thirds of the farmers assessed the idea as interesting and 52% would generally want to use this kind of fertiliser. Another 35% would eventually, and only 14% would generally not want to use these fertilisers. The majority of farmers would accept urine and urine based fertilisers for cereals (91% and 81%, respectively), and one third would even accept those for vegetables. The farmers would also consume cereals (90%) and vegetables (40%) fertilised with urine and urine based fertilisers. Regarding health risks, 32% assessed urine potentially imperiling to health whereas 47% did not esteem it as dangerous.

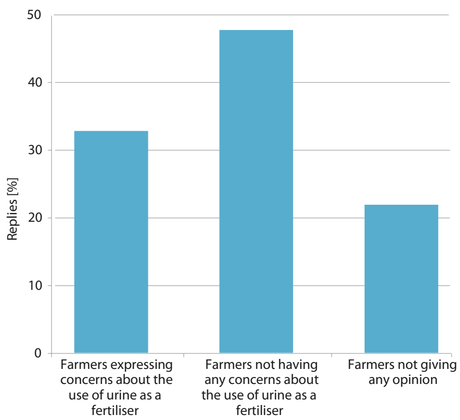

Figure 2: „Do you have any concern regarding the use urine-based fertiliser?"

Around half of the farmers regarded urine as safe, the other half as dangerous; however, three quarters think that its use is controllable.

Nearly two thirds (57%) were not concerned about its use; the doubts expressed by the other third (34%) comprised safety, pharmaceutical residues and consumer acceptance.

4. Conclusions

In general, the idea of the project is appreciated. Due to occurring technical and hygienic problems with the NoMix toilets, people do not want to implement toilets of the current design in their own environment. Farmers were quite interested to apply the new products especially when safety and consumer acceptance can be assured. Consumers as well, accepted to a great extent goods produced with recycled nutrients. From the results of the surveys it can be concluded that users should get involved into the innovations very early and should be informed about the usage and implementation objectives of NoMix toilets as well as about fertiliser use in order to improve the overall acceptance of NoMix toilets and their products.

5. Acknowledgments

This research was realized within the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry for Education and Research), fund No. 02WD0948 and 49. The authors thank the BMBF for the financial support.

Authors: Manfred Romich, Lisa Schiele, Christian Wortmann, Ute Arnold, Katrin Spoth

Responsible partner: Institute of Sociology
RWTH Aachen University
Eilfschornsteinstr. 7
52056 Aachen, Germany

Institute of Crop Science and
Nutrient Conservation
Bonn University
Karlrobert-Kreiten-Str. 13
53115 Bonn, Germany

Publisher: Coordination by Deutsche Gesellschaft
für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

SANIRESCH

Research Project SanitaryRecycling Eschborn (SANIRESCH)

Project component: Agricultural Production / Legal Situation

1. Background

One basic principle of new sanitary systems is reuse and closing nutrient and water cycles. Therefore an appropriate and efficient reuse of nutrients and water - preferably in agriculture - is quite important. In the project several aspects of agricultural reuse were examined.

2. Material and methods

Two products of the GIZ sanitary system were evaluated more closely: (1) GIZ-urine collected from urinals and toilets, after storage and (2) struvite (Magnesium-Ammonium-Phosphate, MAP) produced from this urine.

To evaluate the fertiliser potential of the new products from the GIZ sanitary system, field experiments were conducted in the years 2010-2012 at the field research centre of Bonn University, at Campus Kleinaltendorf. The area is situated in the lower Rhine basin, 20 km west of Bonn, and due to fertile soils and a favourable climate (yearly mean: 9.2 °C, 596 mm precipitation), one of the famous fruit production areas in Germany. There, stored GIZ-urine and produced struvite were applied to different field crops, e.g. summer wheat, maize, fava bean and miscanthus (see Figure 1).

To find out more about the plant uptake of unwanted – potentially toxic – substances from urine, controlled conditions were provided in the greenhouse. Selected pharmaceuticals and hormones were spiked into urine and added to the soil of wheat seedling growing in 10 L-pots. Agents were added in a concentration found in urine (0.5 mg l^{-1}) and 10 times higher. Furthermore, the impact of urine and its components on germination was evaluated for different seeds (wheat, sunflower, fava bean) in germination experiments in the greenhouse.

3. Results and discussion

3.1 Fertiliser properties

Urine and MAP proved excellent fertiliser properties.

- Yields were generally higher compared to the variation without any fertiliser application.
- In comparison to commercially available mineral fertiliser (Calcium ammonium nitrate and Triplephos, respectively), yields of wheat, maize and fava bean did not differ significantly.

Figure 1: Harvest of wheat fertilised with urine.

3.2 Pharmaceutical residues

- In grain samples from the field experiment no pharmaceuticals could be detected. Estrogenic activity was equal in all samples irrespectively of the fertiliser applied.
- No pharmaceuticals were detected in variants of the pot experiment fertilised with urine only.
- One out of four additionally applied pharmaceuticals was determined in corn and stalks: Carbamazepine in grain at concentrations of 5 µg kg^{-1} after application of a typical urine concentration and 30 µg kg^{-1} at a 10x higher concentration.
- The analysis of the other three active ingredients spiked to urine, diclophenac, atenolol and verampamil was negative (below the limit of detection of 1 µg kg^{-1}).

So, technically, pharmaceutically active agents may pass into the plant. However, the concentrations are quite low. Comparing the amount of carbamazepine found in wheat grain with medical prescriptions, a person consuming the average German amount of ~100 kg cereals a^{-1}, would have to eat wheat for more than hundred years to reach the amount of one tablet given per day to a person suffering from epilepsy (400 mg d^{-1} and more).

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3.3 Impact on Germination

Figure 2: Germination test with sunflower (left) and wheat (right).

Urine inhibited germination of seeds when applied directly to the seeds; this effect was not visible in the field where the fertiliser was buffered by soil (see Figures 2 and 3).

- Highest germination rates were achieved with diluted urine (1:100) - slightly higher than those seeds watered with tap water. Undiluted urine inhibited germination completely.
- Pharmaceuticals – applied even in 100-times higher concentrated than usually found in urine – did not cause any negative effect on plant germination.
- pH variations influenced germination of some seeds: wheat germination was partially reduced at alkaline pH (pH 9, 11).
- A strong influence of salts on germination was evident when salts typically present in urine (especially NaCl, NH4NO3, K2HPO4) were at concentrations of GIZ-urine.

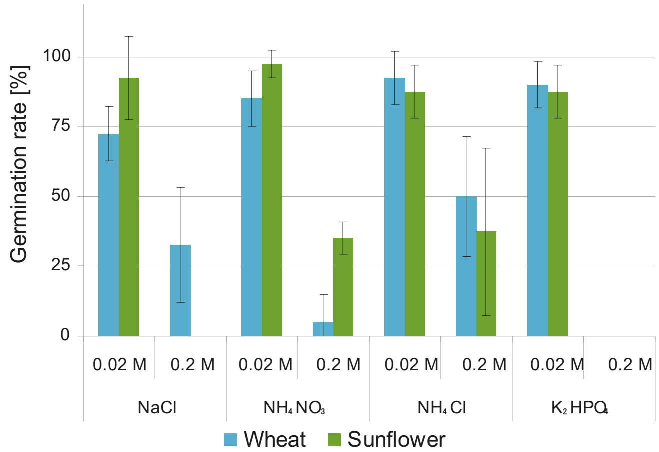

Figure 3: Salt effects on germination.

3.4 Legal Situation

To apply urine or urine based products as a fertiliser in Germany, it needs to be approved in the "positive list" of the German Düngemittel Verordnung (DüMV, 2000) which it is not right now. For being accepted in that list, a request has to be made to the Federal Ministry of Food, Agriculture and Consumer Protection (BMEVL). The application needs to give details on origin, nutrient concentrations and has to prove that the product is non-hazardous. Regarding the appraisal, experts of the Düngemittelbeirat are supporting the ministry.

4. Conclusions

Technically, urine and struvite out of urine contain valuable nutrients, both proved excellent fertiliser properties. For being a tradable product, the legal acceptance still needs to be gained.

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6. Acknowledgments

This research was realised within the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry for Education and Research), fund No. 02WD0948. The authors thank the BMBF for the financial support. The authors also thank Helmut Rehkopf from Campus Kleinaltendorf for conducting the field experiments, Margrit Reich from TUHH for the analysis of pharmaceuticals, Le Anh Thi Hong and Maria A. Escobar for the analysis of estrogenic compounds, Joachim Clemens for first initiating the project and Heiner Goldbach, head of the institute, for his support.

Authors: Ute Arnold, Judith Schmidt

Responsible partner: Institute of Crop Science and Nutrient Conservation
Bonn University
Karlrobert-Kreiten-Str. 13
53115 Bonn, Germany

Publisher: Coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

SANIRESCH

Research Project SanitaryRecycling Eschborn (SANIRESCH)
Project component: Economic Feasibility

1. Background

In this project component, the investment and reinvestment costs of the system and the running costs for its operation were determined. Additionally, the system was compared with a conventional system to find out the overall costs for implementing such a system as well as to determine the most vulnerable and sensitive parameters which might result for or against the selection of such an implementation.
Moreover, two ways of urine reuse that have been investigated in the project "application of urine after storage" and "MAP (Magnesium-Ammonium-Phosphate) precipitation and utilisation of the product in agriculture" were analysed and compared with the costs for applying a mineral fertiliser.

2. Material and methods

The dynamic cost comparison of LAWA (2005) identifies the most cost-efficient solution for water and wastewater projects. Based on scenarios the total project costs (TPC), the annual project costs as well as the dynamic project costs of the SANIRESCH scenarios were calculated along the LAWA guidelines. The economic feasibility of the SANIRESCH concept was investigated with two analyses (see Figure 1) which considered the complete office building and not only the middle part within which the alternative concept was implemented.

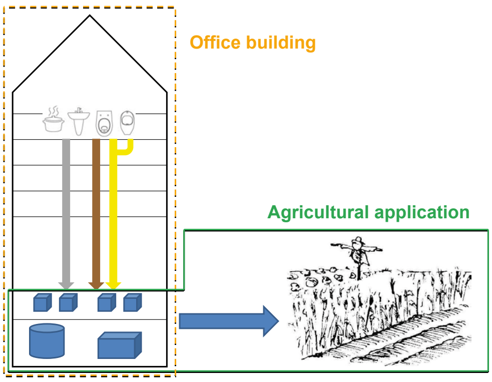

Figure 1: Displays the two systems considered in the economic feasibility analyses, "Office building" and "Agricultural application", with their system boundaries and the areas of overlap.

Economic feasibility analysis „Office building"

Within the analysis "Office building" the following three scenarios were investigated *Scenario A:* SANIRESCH system and the pick-up of the stored urine by the farmer; *Scenario B:* SANIRESCH system with MAP precipitation and direct sale at the building; *Scenario C:* Conventional wastewater system.

Different sensitivity analyses were conducted such as increased automation within the process of MAP precipitation, increased durability of the spare parts of the NoMix toilets and reduced investment costs for sanitary equipment.

Economic feasibility analysis "Agricultural application"

Within the analysis "Agricultural application" three scenarios were investigated combined with different logistic variations *Scenario I:* Urine application after storage within the office building; *Scenario II:* Urine application after storage close to agricultural areas; *Scenario III:* MAP application with storage of MAP within the building; *Scenario IV:* conventional fertiliser application by the mineral fertiliser Calcium-Ammonium-Nitrate (CAN). Different sensitivity analyses were considered such as a decrease of urban land prices in Eschborn, rise of phosphor price and reduction of costs within the MAP production.

3. Results and discussion

The economic feasibility analysis of the office building shows that there is a large difference between the two SANIRESCH scenarios and the conventional one (see Figure 2). The differences come especially through the higher running costs. Their influence is higher than higher investment costs originating from the triple pipe system and higher prices of toilets and urinals.

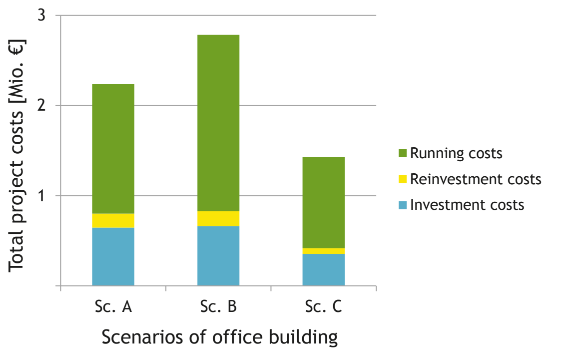

Figure 2: Total project costs of "Office building": A - SANIRESCH with urine application, B - SANIRESCH with MAP precipitation, C - Conventional system.

A high sensitivity is shown within a rising automation of the MAP precipitation process. Currently, 4.35 h/batch of manual labor is required. If the process automation rises up to 75-95%, the TPCs are reduced by 9.8 and 12.4% respectively. However, further aspects have to be adopted before reaching the TPCs of the other two scenarios.

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The rise of durability of the spare parts of the NoMix toilets and a decrease of the investment costs for toilets and urinals result in a clear cost reduction. If spare parts, currently holding an average lifetime of 495 days, last for 30% longer and investment costs are reduced by 25%, the DPCs for scenario A are 6.89 and for scenario B 9.5 €cents/use compared to 6.65 €cents/use of the conventional system. The economic feasibility analysis of the agricultural application showed that due to high land prices within urban settlement areas, storage of urine is much more attractive close to the agricultural areas holding lower land prices (see Figure 3). However, here the transportation costs are much higher. For all scenarios, transport performed by the farmer is always the most economical alternative. Much more expensive than the urine scenarios is MAP production and application. The main cause are the high treatment costs consisting of up to 78% of manual labor costs.

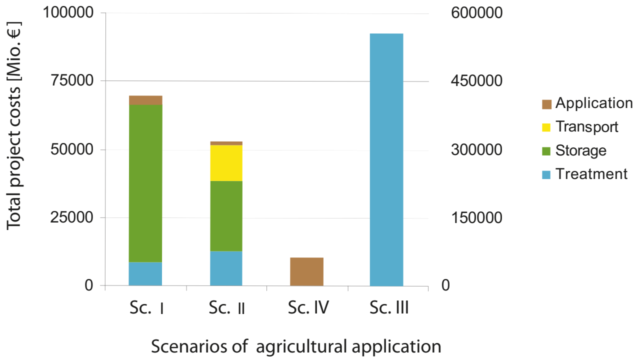

Figure 3: Total project costs for „Agricultural application" of the four scenarios: Direct urine application: I - Storage at GIZ, II - Storage close to fields; III - Production and application of MAP; IV – Application including purchasing of a mineral fertiliser (CAN). The cheapest option of each scenario is shown. Scenario III orients itself at the right y-axis. For further details see Winker et al. (2012).

The fertilising costs per hectare show that comparing the costs for Scenario I-III with Scenario IV, both alternative fertilisers are more expensive. Urine costs result in 748 € ha^{-1}, for MAP 46.800 € ha^{-1} and CAN 124 € ha^{-1} were calculated. While urine still remains in the same range as CAN, MAP is 400 times more expensive, as a result of the high production costs. The sensitivity analyses show clearly that a reduction of the land price in Eschborn from 500 to 100 € m^{-2} would decrease the costs for the urine scenario I to 530 € ha^{-1}. If additionally, a storage without ventilation (leading to less volatilization and thus to higher concentration of nutrients) is considered, the costs for scenario I drop to 228 compared to 296 € ha^{-1} in scenario IV. However, the analysis did not show a severe impact if just the phosphor price increased. When the agricultural scenarios are considered without treatment costs, as already included in the analysis "Office building", the picture changes. TPCs, now including only transport or purchasing and application, for the scenarios with urine application decrease only slightly by 9-24%, where costs of scenario III are reduced by more than 100% showing the potential attractiveness of MAP production.

4. Conclusion and outlook

Comparing the costs for SANIRESCH with today´s costs for conventional wastewater treatment and standard commercial fertiliser, the alternative system is more expensive for both "Office building" and "Agricultural application". However, the sensitivity analyses show that a certain potential exists. With augmented durability of the spare parts of the NoMix toilets in combination with reduced investment costs of sanitary equipment, the alternative scenarios, especially Scenario A can reach the costs of a conventional system. Both changes are reasonable when the development of the toilet and a wider interest in such alternative treatment systems continues. If additionally a higher automation of the MAP precipitation is achieved, Scenario B can become economically feasible as well. Regarding the agricultural application, it is obvious that the urine scenarios can become economically feasible when the conditions of the site are suitable. The use of MAP as a fertiliser is only realisable when the production costs stay below those for commercial phosphorus fertiliser.

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6. Acknowledgements

This research was realised within the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry for Education and Research), fund No. 02WD0947. The authors thank the BMBF for the financial support and Andrés Lazo Paéz, Christina Braum, Lisa-Marie Bischer and their supervisors for their valuable contributions.

Authors: Martina Winker, Ute Arnold, Enno Schröder

Responsible partner: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Sustainable sanitation programme
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

Publisher: Coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

SANIRESCH

Research Project SanitaryRecycling Eschborn (SANIRESCH)
Project component: International Adaptability

1. Background

The analysis of the international adaptability of the three treatment systems designed for and used within the SANIRESCH project specifically focused on developing countries. The systems are a Magnesium-Ammonium-Phosphate (MAP) precipitation reactor and two membrane bioreactors (MBRs) treating the grey- and brownwater.

The aim was to identify regions and typical situations that are suitable for the implementation of the concept and its technical design. Additionally, adaptations required for running the treatment plants successfully in emerging and developing countries were identified.

2. Material and methods

As method the utility analysis (UA) was chosen amongst a variety of other multi-criteria-decision making tools. The UA is generally used for comparing and prioritising complex projects or technologies according to a pre-defined target system. In the first step relevant criteria are defined, weighted and allocated with a rating factor. The individual scores of the criteria are calculated by multiplying the weighting factor of the individual criteria with the rating factor. The individual scores are then summed up to the total score (see Table 1).

The criteria that were used in this analysis can be classified as main-criteria and sub-criteria. The main-criteria are *health and hygiene, economic, functional and technical, environmental as well as socio-cultural criteria*. They have been derived from a study regarding sustainability aspects of urban wastewater management (Hellström et al. 2000). Based on the main-criteria a series of relevant sub-criteria were defined and weighted during several expert interviews. The objective was to design UA matrices that can be adapted and used widely to assess the successful implementation of new alternative sanitation systems (cf. Table 1).

Also the UA was used to identify hotspots for the three technologies, where they can be implemented in a global context and demand can be expected. The same matrices were used but reduced containing a selective number of criteria assuring the application of straightforward and, on a global level, easily available data.
The criteria used for the hotspot analyses were: *water scarcity, freshwater quality, nutrient- and fertiliser demand / availability, eutrophication, population density and rate of urbanisation*.

3. Results and discussion

The first result was the design of matrices ready to be adapted and used for the assessment of a successful implementation of such a sanitation system. Table 1 presents an excerpt of such a UA matrix. The full matrices can be accessed on the SANRIESCH website in the respective studies available for downloading: www.saniresch.de/en/publications-a-downloads/results.

Table 1: Excerpt from utility analysis matrix as developed within this project.

ID	Criteria	Weighting	Raiting description	Rating	Score
…	…	…	…	…	x
E	Environmental criteria	30 %			166 [Σ=E1+E2+E3]
E1	Water scarcity	12 %	high = 10; medium = 5; low = 1; no = 0	10	120
E2	Freshwater quality	7 %	high = 10; medium = 5; low = 1; no = 0	5	35
E3	…	11%	high = 10; medium = 5; low = 1; no = 0	1	11
…	…				
Total score					x % = (166 + x) /10

Apart from that, 3 hotspot maps showing the respective technologies were produced. As an example Figure 1 shows a illustration of the combined hotspots of all involved technologies.

The analysis for the MAP precipitation technology showed that the highest scores were achieved by countries with large population numbers, a high demand for food and hence intensive agricultural activities such as India or Mexico. Another result was that countries in Africa generally yielded low scores. This can mainly be explained by the high proportion of subsistence farming with low or non existing demand for nutrient inputs in terms of industrial fertilisers.

The grey- and brownwater MBR processes were examined as well. The two MBR systems are apart from small technical differences similar in their design. Hence, the assessment of their international adaptability also revealed similar results. The results for both plant types were mostly affected by the sub-criteria water scarcity and freshwater quality. Countries within the Middle East and North Africa region such as Jordan, Egypt, Libya, Oman or Israel showed the highest scores.

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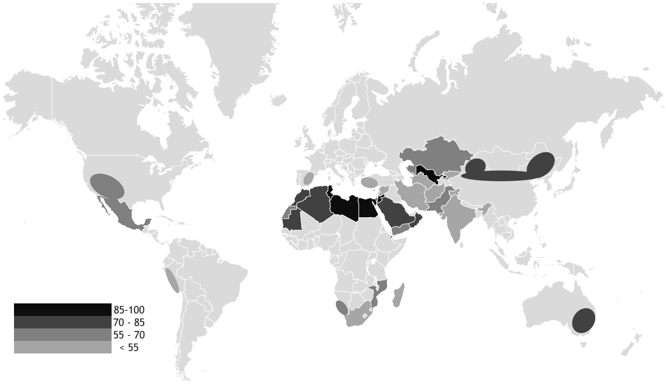

Figure 1: Potential hotspots for the implementation of all three analysed technologies.

Apart from that also countries allocated within Central Asia (e.g. Uzbekistan), parts of South-East Australia, the west coasts of the Americas, India and parts of Southern Africa were identified as hotspots. Due to the potential of reusing nutrients contained in the brownwater, the matrix for that analysis included the criterion nutrient demand. However, it could be proven that this criterion can be neglected when considering the overall assessment.

It could be shown that only nine of the 58 analysed countries can be identified as hotspots for a combination of the three technologies. All of the identified countries are facing water scarcity and have a high nutrient demand due to a large population requiring intensive agriculture. This demand in terms of industrial fertiliser cannot be met by domestic phosphorus resources (see Figure 1). The following group, where two out of three technologies could be identified as appropriate is focused on the MENA region. This combination always consisted of the two MBR systems.

To bridge the gap between the potential demand identified in this project, it is also necessary to consider the prevalent framework conditions. When looking at nutrient recovery (MAP precipitation) the issue of peak phosphorus is crucial. Furthermore, not only fiscal incentives for potential operators, technical aspects such as user-friendly design, permanent power supply and well-trained staff, but also socio-cultural aspects such as sensitisation measures accompanying the implementation process are important to consider.

When focusing more on water treatment and reuse by MBRs, the same fiscal incentives, technical as well as socio-cultural aspects are valid. But unlike the MAP precipitation, in some cases such as in water scarce areas without infrastructure, the MBR systems do provide a strong economic argument.

4. Conclusion and outlook

Overall both, the design of the decision support tool as well as the hotspot analysis reveal a clear picture of the international adaptability of the technologies. Nonetheless, the picture created here does only represent the potential demand side.

In relation with the framework conditions that have been presented, the results become more reliable. However, the actual demand is still subject to further investigations and real life implementation and testing. Finally, it has to be pointed out that aggregated data had been used for the analyses which do not allow detailed regional estimations.

Contemporary trends like climate change involving regional increases of droughts, an exponentially growing population demanding both more water and food and especially relevant for developing countries, the constantly growing trend of urbanisation requiring more space-efficient wastewater treatment technologies articulates the relevance and meaningfulness of this research area.

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Acknowledgment:

This research was realised within the research project SanitaryRecycling Eschborn (SANIRESCH) and supported by the BMBF (Federal Ministry for Education and Research), fund No. 02WD0947. The authors thank the BMBF for the financial support. We also thank Katharina Löw, Yue Wu, Jingjing Peng and their supervisors for their valuable contributions.

Authors: Enno Schröder, Martina Winker

Responsible partner: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Sustainable sanitation programme
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

Publisher: Coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany

I: www.saniresch.de/en
E: saniresch@giz.de

October 2012

Published by:	Project coordination by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH Dag-Hammarskjöld-Weg 1-5 65760 Eschborn, Germany I: www.saniresch.de/en E: saniresch@giz.de
Place and date of publication:	Eschborn, October 2012
Editors:	Enno Schröder, Martina Winker
Design:	Cornelia Eißer, dotwerkstatt Berlin www.dotwerkstatt.de