Comparing the treatment efficiency of different wastewater treatment technologies in Uganda

If operated and maintained properly vertical flow constructed wetland systems can fulfil the stringent Ugandan effluent requirements regarding ammonia nitrogen effluent concentrations.

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Abstract

The data presented in this paper are focusing on the performance of 5 wastewater treatment systems (2 vertical and 2 horizontal flow constructed wetland (CW) systems and 1 waste stabilization pond) in Uganda. The four CW systems, sizes ranging from 200 to 1000 person equivalents, are all a component of sustainable / ecological sanitation systems.

This study demonstrates that vertical flow CWs show a significantly better performance than the commonly constructed stabilisation ponds. They can be a suitable alternative for wastewater treatment particular for rural areas in Uganda. However, still even minimal maintenance requirements of a vertical flow constructed wetland can pose a problem.

Introduction

In 1998-99 the first vertical flow constructed wetland (CW) system was implemented in Uganda. It was constructed for St. Kizito Hospital Matany, a rural hospital in Western Uganda. Since then, six more CWs (2 horizontal and 4 vertical flow CWs, respectively) have been constructed for different institutions scattered all over the country. These seven CW systems, sizes ranging from 200 to 1000 person equivalents, are all a component of sustainable / ecological sanitation systems. These systems focus on water resources protection, in areas where water is very scarce, and reuse of sanitized human excreta and treated wastewater.

The practise of reuse also bears risks to human beings, animals and the environment. To evaluate the actual health risk related to handling and use of treated wastewater and human excreta the study „Risk of Reuse - Study on the reuse of treated wastewater and sanitised human excreta in Uganda“ (Muellegger, 2010) was conducted. Five Ugandan institutions - three hospitals, one health centre and one school - were part of this study. These institutions are using wastewater and products from human excreta in agriculture.

The data presented in this paper are focusing on the performance of the 5 wastewater treatment systems (2 vertical and 2 horizontal flow CWs and 1 waste stabilization pond). The risk assessment which is based on the methodology adopted by the "WHO Guidelines for the safe use of wastewater, excreta and greywater" (WHO, 2006) is not described here. The data of this study have been already presented by Muellegger and Lechner (2011).

Key messages:

- Only vertical flow constructed wetland (CW) systems can fulfil the requirements regarding ammonia effluent concentrations of the Ugandan regulations.
- Vertical flow CW systems show a good performance as long as maintained regularly.
- Even simple operation and maintenance tasks as required for CW systems can be a problem in rural areas of Uganda.
- Design of CW systems in Uganda needs to take into consideration that usually specific grain size distributions for sand are not available locally; the main layer of CW systems has to be constructed with the sand that is available.
- Design organic loads of more than 50 g COD/m²/d are not recommendable as they may lead to clogging.

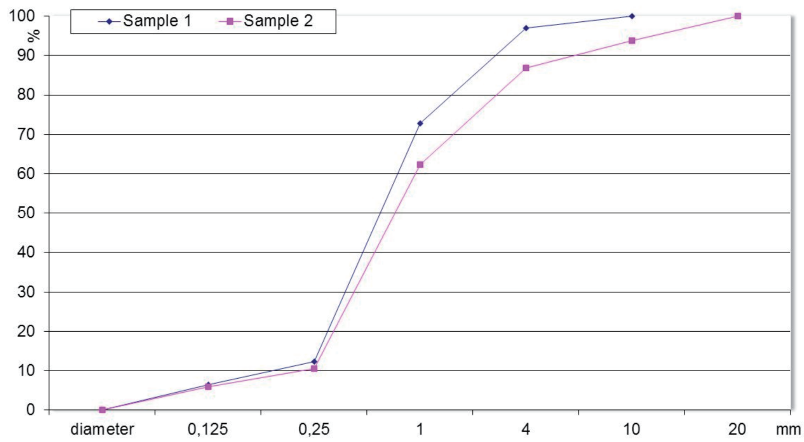

Figure 1: Sieve Analyses Filter Sand at Matany Hospital

Picture 1: Vertical flow CW system in Matany Hospital.

Materials and methods

Site descriptions

Five Ugandan institutions were part of this study: St. Kizito Hospital Matany and Kanawat Health Centre, St. Mary´s Hospital Lacor and Maracha Hospital and Kalungu Girls Secondary School.

St. Kizito Hospital Matany is a rural hospital in the semiarid region of Karamoja, in eastern Uganda. The sanitation system is in operation since 1999. Wastewater from flush toilets and showers is treated in a vertical flow constructed wetland system (Picture 1), with a capacity of 625 PE. The wetland is separated in three individual beds and planted with elephant grass (Pennistum purpureum). A three-chamber settling tank serves as wastewater pre-treatment and a mechanical distribution unit enables an intermittent distribution to the three beds. The treated wastewater is collected in a storage tank for irrigation. Furthermore dried sludge from septic tanks and pit latrines is used as soil conditioner. Both fractions are only used to fertilise trees. The plant was designed for an organic load of 47 g COD/m²/d. For this and all other treatment plants described below locally available sand was used for the construction of the filter. The quality of the sand varies; in the case of Matany Hospital’s treatment plant the grading curve is shown in Figure 1.

Kanawat Health Centre is located in the north-east of Karamoja. The sanitation system was completely replaced in 2003 and 2004. Wastewater from flush toilets is treated in a horizontal flow constructed wetland system (Picture 2), with a capacity of 30 PE. The filter bed is planted with elephant grass. A three-chamber settling tank is pre-treating the wastewater and a sludge drying bed was constructed for stabilised sludge from the settling tank. An underground collection tank is storing the treated wastewater for irrigation of trees. Staff of the health centre is using urine diverting dry toilets, one block with four units. The treatment plant was designed for an organic load of 53 g COD/m²/d.

Maracha Hospital is a rural hospital in north-western Uganda. The sanitation infrastructure was rehabilitated in 2001 and 2002. Wastewater is treated in a vertical flow

Picture 2: Horizontal flow CW system in Kanawat Health Centre.

Picture 3: Filter baskets as wastewater pre-treatment in Maracha Hospital.

Picture 4: Horizontal flow CW system in Kalungu.

Picture 5: Inlet into the first pond in Lacor Hospital.

constructed wetland, which has a capacity of 250 PE. The bed is planted with elephant grass. Two intermittently fed filter baskets are serving as pre-treatment (Picture 3) and a distribution chamber enables an even distribution to the filter beds. Treated wastewater is discharged to the environment. Additionally two blocks of urine diverting dry toilets, each with eight toilets, are in use. Sludge from the filter baskets and dried faeces from the urine diverting dry toilets are composted and used in the hospitals own vegetable garden and sold respectively. The treatment plant was designed for an organic load of 65 g COD/m²/d.

Kalungu Girls Secondary School is a rural boarding school in the tropical South of Uganda. The sanitation system is in operation since 2003. Wastewater is treated in a horizontal flow constructed wetland (for 165 PE), planted with elephant grass (Picture 4). The system is treating mainly greywater and a small share of blackwater from three flush toilets. The collected wastewater is pre-treated in a three-chamber settling tank. After treatment it is infiltrated into the ground and not reused as the amount of water is very little. For excreta management 45 single vault urine diverting dry toilets for pupils and one for teachers are in use. The collected faecal material is further treated in a composting area. Dried faeces and urine are used as fertiliser in the school garden. The treatment plant was designed for an organic load of 160 g COD/m²/d.

Lacor Hospital is a rural hospital in Northern Uganda. A conventional pond system (Picture 5) for treatment of mixed wastewater is in operation since the 1990s. In 2005 a "natural filter" has been constructed, because of insufficient treatment of wastewater. The "natural filter" is a fenced area planted with elephant grass, aiming to increase the treatment efficiency of the system. Treated wastewater is not used.

Determination of quality parameters

Sampling and analysis

Grab samples have been taken 6 times between June 2004 and March 2006 from the effluents of the CWs. During the first three sampling rounds most of the wastewater parameters were analysed directly on spot with field testing equipment. Due to problems of transporting the testing equipment by bus, for the last three rounds the majority of parameters were analysed in the laboratory of the National Water and Sewage Corporation (Quality Control Department; Central Public Laboratories) in Kampala.

The following physical and chemical parameters have been analysed: COD, BOD_5, NH_4-N, PO_4-P, SO_4-S, turbidity, pH-value, electrical conductivity (EC) and temperature. Additionally the samples have been analysed for the following heavy metals: cadmium, chromium, copper, lead, nickel, zinc.

Ugandan Discharge Regulation

For the results of the data collection the Standards for discharge of effluent and wastewater in Uganda (Uganda Discharge Regulation, 1999; Table 1) were used as reference.

Results and discussion

Physico-chemical parameters

Vertical flow constructed wetlands

Table 2 compares the results of the two vertical flow CWs which are both located in the semiarid part of Uganda. The CW in Matany is working since 12 years without problem which was confirmed by the low outflow concentrations. The CW in Matany is using a septic tank as pre-treatment unit, which is emptied once a year. The Maracha CW, on contrary, had continuous problems with the pipe valves of the

Table 1: The standards for discharge of effluent and wastewater in Uganda (The Water (Waste) Discharge Regulations, 1998).

Uganda Discharge Regulation (1999)					
Physico-chemical parameters			**Heavy metals**		
COD	mg/L	100	Cd	mg/L	0,1
BOD5	mg/L	50	Cr	mg/L	1
NH4-N	mg/L	10	Cu	mg/L	1
PO4-P	mg/L	10	Pb	mg/L	5
SO4-S	mg/L	500	Ni	mg/L	1
Turbidity	NTU	300	Zn	mg/L	0,1
Ph value	-	6-8			
El. conductivity	µS/cm	--			
Temperature	°C	--			

distribution chamber. This was mainly due to the fact that maintenance of the system was neglected. The non-functional pipe valves are mainly responsible for a lack of oxygen thus resulting in a higher NH_4-N effluent concentration.

Horizontal flow constructed wetlands

Table 3 compares the results of the two horizontal flow CWs. Both are in operation since nearly eight years and are used mainly to treat greywater. The treatment system in Kanawat had only problems with too high NH_4-N concentrations which could be attributed to unplanned urine discharge into the sewer system. The analysis in Kalungu showed very unsatisfactory results. The main reasons are the instability of the hydraulic load, which fluctuates strongly over the year and the comparatively high design load. Especially during holidays, the hydraulic load is reduced to a minimum and the wetland oversized while during school the system is overloaded.

Vertical flow vs. horizontal flow CW

The results presented in Table 2 and Table 3 demonstrate the expected improved nitrification efficiency of vertical flow constructed wetlands. The untypically high NH_4-N effluent concentration of the

Table 2: Characteristics of the vertical flow CW effluents.

VERTICAL FLOW CW		MATANY			MARACHA		
Parameter		#	Average	Stdev	#	Average	Stdev
Physico-chemical paramters							
COD	mg/L	6	86	48	5	130	70
BOD5	mg/L	4	20	14	2	14	2
NH4-N	mg/L	3	1,4	0,5	5	43,4	28,2
PO4-P	mg/L	5	7,8	1,9	6	10,0	14,7
SO4-S	mg/L	3	34,7	6,1	3	26,7	6,0
Turbidity	NTU	4	7,1	9,1	4	17,0	15,6
Ph value	-	5	7,1	0,7	5	6,8	1,2
El. conductivity	µS/cm	5	1550	147	5	1841	360
Temperature	°C	4	25,8	2,1	4	26,2	1,8

Table 3: Characteristics of the horizontal flow CW effluents.

HORIZONTAL FLOW CW		KANAWAT			KALUNGU		
Parameter		#	Average	Stdev	#	Average	Stdev
Physico-chemical paramters							
COD	mg/L	6	87	31	5	121	31
BOD5	mg/L	3	22	4	3	65	7
NH4-N	mg/L	6	46,6	27,3	5	29,2	15,1
PO4-P	mg/L	5	5,8	2,4	4	7,5	5,5
SO4-S	mg/L	3	43,3	9,0	2	34,5	6,4
Turbidity	NTU	4	18,8	22,1	3	34,0	27,6
Ph value	-	5	7,7	0,2	4	7,4	0,6
El. conductivity	µS/cm	5	2046	375	4	1145	332
Temperature	°C	4	24,4	2,6	5	23,9	2,5

Maracha treatment plant is due to maintenance issues. Frequent problems with keeping the pipe valve, which controls the intermittent discharge to the filter beds, operational result in insufficiently equal distribution of the wastewater and lack of oxygen supply into the soil matrix.

Pond system

Table 4 shows the results of the pond system in Lacor. The results show significantly higher effluent concentrations for COD, BOD_5 and NH_4-N in comparison to constructed wetlands. Higher COD and BOD concentrations are probably at least partly due to algae which can not be retained in the system (compare the lower COD/BOD ratio compared to constructed wetlands as well as higher turbidity) while the higher NH_4-N concentration shows insufficient supply of oxygen for nitrification.

Table 4: Characteristics of the pond system effluent.

PONDS		LACOR		
Parameter		#	Average	Stdev
Physico-chemical paramters				
COD	mg/L	6	176	78
BOD5	mg/L	3	65	23
NH4-N	mg/L	6	59,9	15,8
PO4-P	mg/L	6	6,3	3,5
SO4-S	mg/L	3	5,0	2,6
Turbidity	NTU	4	68,3	37,0
Ph value	-	5	6,7	1,2
El. conductivity	µS/cm	6	918	278
Temperature	°C	5	23,7	2,7

Heavy metals

The analysis for heavy metals showed that in most samples the concentration was below the Ugandan standards, only few samples exceeded the limits. Scattered higher levels of copper, nickel, cadmium and lead have been measured. The main sources of high lead, cadmium and nickel concentrations in wastewater are discarded nickel-cadmium (WHO, 2003) and lead-acid (WHO, 2008) batteries thrown into the toilets. High copper concentrations may result from corrosion of interior copper plumbing, which may occur in standing water in copper pipes (WHO, 2008).

Operation and maintenance (O&M) as key factor for sustainability

Maximum benefit of an improved sanitation infrastructure can only be achieved when the facilities operate continuously and at full capacity in conformity with national standards of quantity and quality. In practice, O&M of sanitation systems, especially in developing countries, receives less attention compared to the design and construction phases, or it is even completely neglected (Muellegger et al. 2010; Hierzegger et al., 2012). The CWs in Uganda proof these statements:

- Matany Hospital and Kanawat Health Centre have employees who are responsible for the CW systems. Besides the regular maintenance works they are also emptying the septic tank once a year, resulting in well performing CW systems.

- In Maracha Hospital also operators for the sanitation system are employed. However, the distribution chambers are not cleaned regularly thus the pipe valves are not working, resulting in poor performance. A similar problem exists in Kalungu, where the septic tank is not cleaned regularly.

Recommendations for implementation of CWs in Uganda

Commonly it is assumed that technical wastewater treatment plants are not applicable for (rural areas in) Uganda. The main reasons are unreliable power supply and lack of technical capacities for operation and maintenance. Therefore commonly stabilisation ponds are designed as a standard solution. However looking at National Standards (The National Environment Regulations, 1999) and expected and measured performance of stabilisation ponds it is clear that as far as nitrification is concerned these standards cannot be reached. This study demonstrates that vertical flow constructed wetlands show a significantly better performance and can be a suitable alternative for wastewater treatment in particular for rural areas in Uganda. Still even minimal maintenance requirements of a vertical flow constructed wetland - in the case of the treatment plant in Maracha the pipe valve for intermittent discharge - can pose a problem.

Nevertheless further research is required when it comes to nitrogen elimination as required according to Ugandan National Standards (Total N <10mg/L; The National Environment Regulations, 1999). Furthermore one major issue related to technical design is the quality of filter media available locally. While European design guidelines generally assume the availability of uniform filter media this is not the case in Uganda. Material which is available locally or at least within close vicinity has to be used for cost and logistical reasons. A design methodology therefore by necessity should take the characteristics of the material into consideration rather than assuming a certain quality.

References

Hierzegger, H., Lang, B., Jung, S., Wafler, M. (2012): Looking back on implementation projects from the last 10 years. Sustainable Sanitation Practice 10 (Jan 2012), 6-13.

Muellegger, E. (2010): Risk of Reuse - Study on the reuse of treated wastewater and sanitised human excreta in Uganda. Master thesis, University for Natural Resources and Life Sciences, Vienna (BOKU University), Austria.

Muellegger, E., Freiberger, E., McConville, J., Samwel, M., Rieck, C., Scott, P. Langergraber, G., (2010): Operation and maintenance of sustainable sanitation systems. Fact sheet SuSanA Working Group 10, Sustainable Sanitation Alliance (SuSanA), http://www.susana.org.

Muellegger, E., Lechner, M. (2011): Constructed wetlands as part of EcoSan systems: 10 years of experiences in Uganda. Newsletter of the Specialist Group on Use of Macrophytes in Water Pollution Control, No.38, June 2011, 23-30.

The National Environment Regulations (1999): Standards for Discharge of Effluent into Water or on Land. Statutory Instruments Supplement No.5/1999, Kampala, Uganda.

The Water (Waste) Discharge Regulations (1998), Statutory Instruments Supplement No.32. 1998, , Kampala, Uganda.

WHO (2003): Nickel in Drinking-water. Background document for development of WHO Guidelines for Drinking-water quality, World Health Organisation, Geneva, Switzerland (http://www.who.int/water_sanitation_health/dwq/chemicals/nickel.pdf).

WHO (2006): WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater. Volume II Wastewater use in Agriculture. World Health Organisation, Geneva, Switzerland.

WHO (2008): Guidelines for Drinking-water Quality. Third edition, incorporating the first and second addenda, World Health Organisation, Geneva, Switzerland.

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