Screening of different types of on-site sewage facilities - treatment function and potential for removing micropollutants

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Abstract

On-site sewage facilities (OSSF) in Sweden were investigated to check the treatment function and determine the potential for removing micropollutants (MPs). The 16 OSSFs studied included soil filtration systems (SFS), package treatment systems (PTS) and source separation of sewage (SSS). Two medium-sized municipal wastewater treatment plants were also included for reference. Nitrogen (N), phosphorus (P), dissolved organic carbon (DOC) and MPs were analysed. For SFS, overall removal efficiency of nitrogen and phosphorus was acceptable, but some individual facilities showed poor treatment results. This was generally attributable to lack of maintenance, which affected removal performance for most parameters tested. No-target screening for MPs, carried out in laboratories at Umeå University (UU) and the Swedish University of Agricultural Sciences (SLU), revealed average removal efficiency of 52.4% for SFS and 37.5% for PTS. Thus MPs can be removed by on-site sewage systems, but higher removal efficiency is needed.

Keywords

On-site sewage facility (OSSF); soil filtration system (SFS); package treatment system (PTS); source separation sewage (SSS); micropollutants (MPs)

INTRODUCTION

There are strict requirements on the quality of discharge wastewater from wastewater treatment plants (WWTPs). Large-scale municipal WWTPs are able to utilise advanced technology to meet these quality requirements, but there are around 75 300 households in Sweden (representing 10% of the population) that are not connected to a municipal WWTP. These households release 295 tons of phosphorus and 3066 tons nitrogen per year in treatment effluent (Olshammar, 2015). An investigation in 2015 by Swedish Environmental Emissions Data (SMED) found that around 83% of the Swedish households concerned have combined sewers and 17% have source separation sewage (SSS) (Olshammar, 2015). Of the combined sewer systems, 48% use a soil-based facility known as a soil filtration system (SFS) (Olshammar, 2015). The most common type of SFS comprises a three-chamber sludge separation tank, followed by either a constructed sand filter or an infiltration bed (Eveborn, 2013). A constructed sand filter consists of a diffusion layer to spread the wastewater evenly, a sand layer for filtration and outlet pipes to collect the effluent water. A construction has an impermeable bottom layer and effluent can therefore be controlled and monitored. The infiltration bed only has a diffusion layer conducting the wastewater to natural soil for filtration and there is no collection system for the effluent, so there is a risk of wastewater entering the groundwater before it is well treated.

Other treatment methods used in combined sewers include the package treatment system (PTS), which has become more popular in recent years. The PTS treatment process varies with different suppliers, but usually includes chemical dosing, aeration, precipitation and so on. In 2009, the County Administration Boards in Sweden carried out a study on 24 different types of PTS in which effluent water samples from 115 PTS were taken for chemical and biological analysis. The results showed that the average BOD_7 value was just within the normal limit according to recommendations by the Swedish Environmental Protection Agency (SEPA), but that the concentration of total phosphorus exceeded the limit (Hubinette, 2009).

In addition, a large number of households in Sweden (125 000) still only have a three-chamber sludge separation tank, a sewage system that has been illegal since the 1960s (Olshammar, 2015).

Overall, 11% of the combined sewer systems involve source separation of sewage (Olshammar, 2015), where blackwater and greywater are collected separately. The septic tank is emptied periodically and the contents are transported to a municipal WWTP. Greywater is discharged directly to ditches and ends up in natural surface waters.

In 2006, SEPA released updated guidelines for small sewage plants that recommend two protection levels (normal, high), in order to comply with human health and environmental considerations (Table 1). The degree of protection required at each level is based on conditions in the area.

Table 1. Normal and high protection levels for on-site sewage facilities according to SEPA (2006)

	Normal level	High level
BOD_7	90% reduction /30 mg/L	90% reduction/30 mg/L
P_{tot}	70% reduction/3 mg/L	90% reduction/1 mg/L
N_{tot}	-	50% reduction/40 mg/L

BOD_7 = biological oxygen demand, P_{tot} = total phosphorus, N_{tot} = total nitrogen.

However, it is difficult to apply the SEPA recommendations to on-site sewage facilities (OSSFs), as various factors make it difficult to check effluent water quality. For instance, the infiltration system releases the effluent directly to the groundwater, which make it impossible to take samples for analysis. In addition, many of the existing OSSFs were built several decades ago and are now ageing and in need of maintenance, e.g. the sand in the filter may need to be replaced. Moreover, wastewater may leak out from the sand filter and rain water may leak in (Eveborn, 2012), while in order to guarantee good treatment the impermeable bottom layer may need to be fixed.

The aim of this study was to evaluate the function of a number of existing OSSFs in Sweden and identify their potential for removing micropollutants (MPs). Micropollutant removal from wastewater has attracted greater research interest in recent years, but little work has been done on the removal rate in OSSFs. Earlier studies have investigated different materials and technologies to remove a few target MPs (for example Teerlink. 2012; Matamoros, 2009). The objective in the present investigation was to provide a systematic overview of the efficiency of current treatment methods in removing a wide range of MPs.

MATERIAL AND METHOD

Sampling

Wastewater grab samples were collected from both influent and effluent flows at 16 OSSFs in Sweden in October-November 2013. In order to cover a range of different OSSF types, the selected systems comprised several different treatment technologies. Water samples from two medium-sized municipal WWTPs were also taken, as reference. The types of systems investigated and their locations were:

- SFS: Skravelsjö, Bornsjön 3*, Brottby 1**, Odensala Berga, Backa Gård, Tärby Gård, Obbla, Bjännsjö, Markim
- PTS: Filipsbol, Bjännberg, Brottby 2, Bröllstaby
- SSS: Nybble, Bornsjön 1, Bornsjön 2
- WWTP: Roslags Kulla, Sävar

* Water samples taken from three OSSFs at Bornsjön, one SFS and two SSS.

**Water samples were taken from two OSSFs at Brottby, one SFS and one PTS.

The nine SFS selected included three different types: traditional SFS; traditional SFS with a phosphorus filter (Polonite) as an extra polishing step; and SFS using crushed clay aggregates (Filtralite) as the filter medium instead of sand. All nine SFSs use a constructed sand bed for filtration. Although the infiltration bed plays a large part in Swedish OSSFs, as mentioned above it is impossible to obtain effluent samples due to its construction. The treatment process at the four PTS studied includes a sequence batch reactor (SBR) and continuous flow reactor. Blackwater samples were taken from septic tanks at two locations and greywater samples at three locations.

Analysis

To assess the function of the on-site treatment systems, the control parameters total nitrogen, total phosphorus, dissolved organic carbon (DOC), pH value, electrical conductivity (EC), turbidity and oxygen concentration in influent and effluent of SFS, PTS and WWTP were analysed.

For analysis of MP removal, no-target screening was carried out by laboratories at Umeå University (UU) and the Swedish University of Agricultural Sciences (SLU). Since only one influent and one effluent grab sample were taken from each site, to achieve more representative results the MP analyses were performed on four pooled samples of influent/effluent water from each type of system, which were mixed immediately before analysis. These samples represented pooled influent water from SFS and PTS and pooled effluent water from SFS and PTS. Common control parameters were also analysed for these samples to evaluate whether each type of OSSF was working in a satisfactory manner.

RESULTS AND DISCUSSION

Due to some practical problems and sampling errors, we were unable to analyse all control parameters in all samples and therefore there are a few gaps in the data, e.g. only two PTS were analysed for control parameters, but all four PTS were included in MP analysis. However, since we used average values for control parameters and pooled samples for MP analysis, the results can still provide a direct overview of the performance of existing OSSFs. Based on the results, further studies are planned.

Control parameter analysis

Determination of control parameters to evaluate the performance of SFS, PTS and WWTP revealed that the OSSFs usually had higher concentrations of pollutants in influent than the conventional WWTPs. The main reason for this is that wastewater arriving at WWTPs is diluted by rainwater. Water quality varied widely between the OSSFs studied, while the quality of both influent and effluent water at the WWTPs was relatively stable.

SFS

The concentrations/values of control parameters in influent and effluent water from SFS are presented in Table 2.

Table 2. Influent and effluent water quality for the eight Swedish soil filtration systems (SFS) studied

Location	N_{tot}			P_{tot}			DOC		
	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
Skravelsjö	68,19	50,23	26,3%	9,89	3,24	67,2%	15,80	8,60	45,6%
Bornsjön* 3	102,06	25,41	75,1%	13,31	2,06	84,5%	26,30	6,90	73,8%
Brottby	8,36	6,63	20,7%	3,79	0,82	78,4%	7,40	27,20	-267,6%
Odensala Berga	125,23	80,15	36,0%	18,51	4,26	77,0%	28,60	14,80	48,3%
Glasögersvägen	53,61	43,22	19,4%	8,23	8,29	-0,7%	50,10	15,40	69,3%
Bjännsjö	51,63	37,11	28,1%	8,31	4,37	47,4%	12,10	5,00	58,7%
Backa Gård	100,43	42,23	57,9%	39,60	0,70	98,2%	69,60	23,60	66,1%
Tarby Gård	63,63	22,13	65,2%	10,37	0,29	97,2%	74,20	35,20	52,6%
Average	71,64	38,39	46,4%	14,00	3,00	78,6%	35,51	17,09	51,9%

The mean concentration of total nitrogen in SFS influent was 71.64 mg/L (range 8.36-125.23 mg/L). The maximum influent value recommended by SEPA (2006) is 80 mg/L, which was exceeded by three SFS. The average concentration of total phosphorus was 14 mg/L (range 8.23-39.60 mg/L). This was slightly above the recommended value of 12 mg/L, which was exceeded by four SFS. The oxygen concentration was low in all cases (0.33-0.80 mg/L) and the average temperature was 10.92 °C (range 7.6-14.8 °C) (data not shown).

The mean removal of total nitrogen achieved the high protection level (40 mg/L) suggested by SEPA (2006). Effluent from Brottby in particular had a very low concentration, but it also had a very low concentration in the influent (Table 2), so the removal efficiency was only 20.7%. Odensala Berga had a high total nitrogen concentration in both influent and effluent, but its removal efficiency was higher (36%).

To guarantee nitrification, an SFS should be functioning aerobically and therefore a good supply of oxygen is important (Palm, 2012). From Table 3, it can be seen that a few sites, such as Brottby and Odensala Berga, had a very low oxygen level in the effluent water (0.65-0.95 mg/L) (data not shown). This may have been caused by clogging of the sand filter.

The average removal of total phosphorus achieved the normal protection level (3 mg/L) suggested by SEPA (2006), but the concentration in Obbla effluent was high (8.29 mg/L). In an efficiently working SFS, a phosphorus removal rate of 85±10% can be expected. Comparison of the influent and effluent concentrations indicated that Skravelsjö, Obbla and Bjännsjö SFS need maintenance work. The removal of dissolved organic carbon was 52%, which could be better. However, turbidity was reduced from on average 134 to 15.33 NTU, which is really good. High pH was observed in the effluent water at a few sites, the reason being that the phosphorus filter that comprises the final step in SFS has calcium silicate as its main component (data not shown).

PTS

Water samples from two PTS (Filipsbol, Bjännberg) were analysed. Filipsbol uses a continuous flow reactor, while Bjännberg uses an SBR reactor. The concentrations/values of control parameters in influent and effluent water from PTS are presented in Tables 3.

Table 3. Influent and effluent water quality for the two Swedish package treatment systems (PTS) studied

Location	N_{tot}			P_{tot}			DOC		
	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
Filipsbol	13,69	17,16	-25,3%	15,94	0,35	97,8%	7,40	6,40	13,5%
Bjännberg	10,25	10,82	-5,6%	1,85	0,45	75,7%	5,80	3,20	44,8%
Average	11,97	13,99	-16,9%	8,90	0,40	95,5%	6,60	4,80	27,3%

Both sites had very low concentration of total nitrogen and DOC. In fact, the concentrations in influent at Bjännberg were extremely low for all factors, indicating that there may have been some sampling error or some dilution of the influent at the time of sampling.

The total nitrogen concentration was even higher in the effluent than the influent but, just judging from the effluent value (13.99 mg/L), the quality was good enough for direct discharge.

WWTP

Of the two medium-sized WWTPs investigated for reference, Rogslags Kulla is designed for 125 person equivalents (pe) and Sävar for 2500 pe. The concentrations/values of control parameters in influent and effluent water from these WWTPs are presented in Tables 4.

Table 4. Influent and effluent water quality for the two Swedish municipal wastewater treatment plants (WWTP) studied

Location	N_{tot}			P_{tot}			DOC		
	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
	mg/l	mg/l	%	mg/l	mg/l	%	mg/l	mg/l	%
Roslags Kulla	43,92	51,26	-16,7%	5,52	0,70	87,2%	13,30	13,80	-3,8%
Sävar	40,61	19,55	51,9%	5,27	0,14	97,4%	22,00	7,90	64,1%
Average	42,27	35,40	16,2%	5,39	0,42	92,2%	17,65	10,85	38,5%

The WWTPs were good at removing phosphorus, but total nitrogen and dissolved organic carbon were not well removed.

Removal efficiency

For the filter systems as groups (SFS, PFS, WWTP), the overall removal efficiency of nitrogen, phosphorus and dissolved organic carbon was acceptable (Figure 1). However, some of the individual systems showed less promising results. This indicates that some OSFFs are not in good condition and need maintenance.

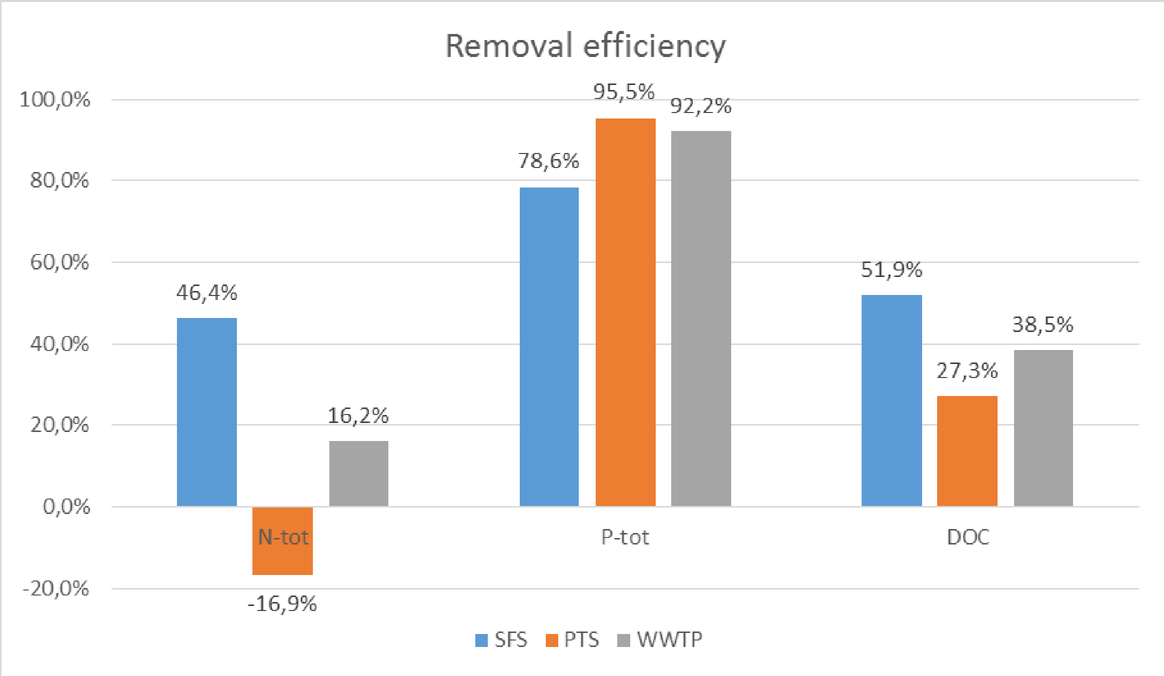

Figure 1. Removal efficiency of total nitrogen (N_{tot}), total phosphorus (P_{tot}) and dissolved organic carbon (DOC) in soil filtration and package treatment systems (SFS, PTS) and in municipal wastewater treatment plants (WWTP) used for reference.

From Figure 1, it can be see that SFS had much better removal efficiency than PTS and WWTP in the case of total nitrogen. All three treatment methods removed a large percentage of total phosphorus. PTS and WWTP being slightly better than SFS. Removal of dissolved organic carbon was rather low for all methods, with SFS being slightly better that the other types of system.

Blackwater and greywater analysis

Blackwater samples for analysis were taken from septic tanks. At Nybble and Bornsjön 2, greywater is discharged without any treatment. At Bornsjön 1, the greywater is diverted to a constructed sand filter. One effluent water sample from Bornsjön 1 was taken to test pollutant removal from greywater by sand filtration. Tables 5 and 6 presents the results for blackwater and greywater, respectively.

Table 5. Blackwater quality for the two treatment systems sampled

Location	N_{tot}	P_{tot}	DOC	pH	EC	Oxygen	Temp	Turbidity
	mg/L	mg/L	mg/L		µS/cm	mg/L	°C	NTU
Nybble	1295.73	95.08	408.75	8.19	1329	0.00	15.90	765
Bornsjön 1	506.08	275.21	143.10	7.49	6940	0.43	12.80	-
Mean	900.91	185.14	275.93		4135	0.22	-	765

Table 6. Greywater quality for the three treatment systems sampled

Location	N_{tot}	P_{tot}	DOC	pH	EC	Oxygen	Temp	Turbidity
	mg/L	mg/L	mg/L		µS/cm	mg/L	°C	NTU
Nybble	8.23	1.03	8.10	7.15	564	1.50	14.80	21
Bornsjön 1	14.05	2.63	18.60	7.53	748	1.89	-	211
Bornsjön 2	10.78	2.44	9.40	7.36	568	1.33	6.50	35
Mean	11.14	1.83	13.35	7.34	656	1.70	-	116

A comparison of Tables 8 and 9 confirmed that blackwater contained high levels of pollutants, while technically greywater is suitable for direct discharge. The concentrations of a few control parameters in greywater were even lower than in treated wastewater from several OSSFs. Table 7 presents the corresponding values for effluent greywater from SFS.

Table 7. Quality of treated greywater from a constructed sand bed filter system (SFS)

Location	N_{tot}	P_{tot}	DOC	pH	EC	Oxygen	Temp	Turbidity
	mg/L	mg/L	mg/L		µS/cm	mg/L	°C	NTU
Bornsjön 1	13.64	1.41	7.50	8.15	645	10.23	4.80	8

Comparing the influent and effluent water quality for greywater, there were no major differences except for turbidity. However, treatment of the greywater still gave an improvement in quality by removing nitrogen and dissolved organic carbon. This was due to the long retention time in the constructed sand bed.

Micropollutant analysis

A total of 45 and 75 MP compounds were detected by the UU and SLU laboratories, respectively. Among the substances detected, 31 compounds, including fragrances, UV stabilisers, food additives, detergent ingredients/other surfactants, plastic/rubber additives, biocides and pharmaceuticals, were selected as case chemicals (Blum, 2016) (Gros, 2016). This selection was based on the removal efficiency, maximum concentration and expert knowledge. For instance, widely detected compounds such as carbamazepine, high concentration compounds such as ibuprofen and low removal efficiency compounds such as lamotrigine were included. Mean removal efficiency for different types of MPs in the SFS and PTS studied are presented in Table 8.

Table 8. Removal efficiency of selected MPs in sand filtration systems (SFS) and package treatment systems (PTS) (Blum, 2016) (Gros, 2016)

	SFS	PTS
Fragrances	68.6%	93.9%
UV stabilisers	55.9%	98.9%
Food additives	69.5%	59.9%
Detergents	46.5%	-6.8%
Plastic/rubber additives	70.7%	66.5%
Biocides	27.3%	14.6%
Pharmaceutical	52.9%	34.1%
Mean removal rate	52.4%	37.5%

Biocides were removed poorly by both SFS and PTP (on average 27.3 and 14.6 % removal, respectively). In SFS, the removal of most other MPs was within the range 55-70%. However, the removal efficiency for PTS varied widely (-6.8-98.9%). PTS was very efficient at removing fragrances and UV stabilisers (94-99%), but poor at removing biocides and pharmaceuticals and there was even negative removal of detergents. Since the analysis was based on pooled grab samples, there is a possibility that some chemicals were not present in the influent water but present in high concentrations in the effluent, explaining the negative removal. Another possibility is that it was caused by by-products from the treatment process. Overall, SFS provided better removal of MPs than PTS.

CONCLUSIONS

This study found that not all OSSFs in Sweden are in good condition, which calls for improved maintenance. On average, SFS provided acceptable treatment results for all control parameters tested and was also better at MP removal than PTS. However, due to the low values of pollutants in influent at some sites even the effluent water quality was good, so efficient function of those systems could not be demonstrated and further studies are needed. In removal of MPs, PTS had a few extreme values, removing almost all fragrances and UV-stabilisers, but showing very low or even negative removal efficiency for detergents, biocides and pharmaceuticals. Micropollutants can thus be removed to varying degrees by OSSFs, but further studies are needed to identify the mechanisms involved.

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