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Sand filters for removal of microbes and nutrients from wastewater during a one-year pilot study in a cold temperate climate

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ABSTRACT

Onsite wastewater treatment systems (OWTS) are recognised as potential threats to groundwater or other water environments subject to discharged effluents. In this study, the microbiological and nutrient removal properties of three different pilot-scale sand filters (SFs) were followed over a one-year period. Moreover, a separate phosphorus removal unit was tested for six months. For the best treatment system, the average log removals were 2.2–3.5 for pathogenic human noro- and adenoviruses and 4.3–5.2 and 4.6–5.4 for indicator viruses and bacteria, respectively. The system that effectively removed microbes was also efficient at removing nutrients. However, the poorest treatment system yielded substantially lower removals. The remarkable differences noted between the studied SFs highlights the importance of construction materials and the careful planning of the filters. Moreover, seasonal conditions appear to have a clear effect on purification efficiencies, emphasising the vulnerability of these systems especially in cold climates.

1. Introduction

Onsite wastewater treatment systems (OWTS) are widely used in rural areas that lie outside the coverage of sewerage systems. Traditionally, rural household wastewater has been treated by two or three separate septic tanks that provide primary treatment, and a soil absorption field for further treatment. However, the risks to groundwater from leaking or improperly functioning OWTS are recognised (Scandura and Sobsey, 1997) and even properly constructed OWTS may cause a waterborne outbreak (Borchardt et al., 2011). The Finnish Onsite Wastewater System Decree (209/2011) requires that rural wastewaters should be properly managed in relation to nutrients and organic load (Government Decree, 2011). In practice, this can be accomplished by the appropriate OWTS, such as conventional buried sand filters (SFs) or commercial package treatment plants such as sequencing batch reactors. The requirements and functionality of the OWTS has been based on their capacity to reduce the nutrients and organic load of wastewaters. However, the microbiological quality of the wastewater treated with these systems is often unknown.

SFs are a sustainable and low-cost alternative for the treatment of rural wastewaters. In addition, SFs operating without electricity might be an economical option to treat wastewaters for many of the 2.5 billion people who still do not have the possibility to use improved sanitation (WHO and UNICEF, 2013). The efficiency of the treatment is mainly based on the physical and chemical properties of the filter and the metabolism of microbes in the developed biofilms. Good SFs require minimal maintenance and have a rather long lifetime. However, the need for careful planning of the systems is important to avoid blockage problems related to the sand material (Kristiansen, 1981). In addition, more knowledge is needed about the effects of filter materials, exceptional loadings and climatic conditions on purification efficiencies, before the environmental and health risks related to SFs can be defined properly.

The fact that treated wastewater can contain pathogenic microbes (Maunula et al., 2009) has raised concerns about the capacities of existing treatments to remove these micro-organisms. In particular, the fate of enteric viruses such as noroviruses is of major interest, since they are common causes of waterborne outbreaks (Zacheus and Miettinen, 2011).

This study assessed the performance of three different SFs over a one-year period that included the four seasons of cold temperate climate. The main purpose was to determine the hygienic

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purification capacities of each system with respect to pathogens and indicators. The functioning of the systems was also evaluated in terms of their ability to remove nutrients and organic load.

2. Materials and methods

2.1. Construction of the SFs and test conditions

Three different pilot-scale SFs were constructed (Fig. 1). In addition, a separate phosphorus removal unit (Nordkalk Filtra P) connected at the end of SF-3 was tested (SF-3+P). This granular P filter material consists of lime, iron compounds and gypsum. The appropriate sizes of the systems were determined either by the manufacturer or the grain size of the sand material, fulfilling the instructions for dimensioning in relation to specific flow. SFs were located in an insulated container whose temperature was kept above zero degrees with an automatic heat blower during winter and cooled to about 15 °C during summer.

2.2. Loading and sampling

The influent loaded into the SFs was raw municipal post-screen wastewater of Kuopio (Finland), from an area serving approximately 86 000 inhabitants and industry. The wastewater was first pumped into a 1000 L tank and allowed to sediment for two days (Fig. 1). The clarified wastewater was pumped into the SFs through infiltration pipes containing pinholes to guarantee a uniform infiltration. The normal load of each SF was 33.3 L d^{-1} based on water consumption of 200 L d^{-1} per capita and the daily flow pattern was according to the European standard (EN 12566-3, 2005). In addition, periods of overloading and underloading were enacted, these being 125% and 50% of the normal load. These exceptional periods continued for one week and both were carried out three times during the study. Percolated wastewater was sampled by collection pipes located at the collection layer of SFs. Every effluent sample was collected over 24 h and taken at three weeks intervals and also one week after under and overloading periods. In total, 20 influent and effluent samples from SF-1–3 were collected over a one-year period (from 12th October 2010 to 25th October 2011). The effect of cold period on the purification efficiencies was studied by comparing eight winter samples collected between 23rd November 2010 and 29th March 2011 to the rest of the samples (summer). In addition, 10 effluent samples from SF-3+P were collected over six months period (from 18th April 2011 to 25th October 2011). The samples were analysed for indicator microbes (*Escherichia coli*, intestinal enterococci, spores of sulphite-reducing clostridia, heterotrophic bacteria, somatic coliphages and F-specific coliphages), pathogenic microbes (campylobacteria, adenoviruses and noroviruses), nutrients (phosphorus, nitrogen) and organic load (BOD, COD and suspended solids).

2.3. Bacteriological analyses

Indicator bacteria were analysed with a filtration method (Millipore membrane filter, pore size 0.45 μm for *E. coli* and intestinal enterococci and Whatman ME 24 ST, pore size 0.2 μm for clostridia) in two replicates. The detection limit of the method was 1 CFU 100 mL^{-1}. For *E. coli*, the detection was done by using the selective ChromoCult Coliform agar (Merck KGaA, Germany) according to the manufacturer's instructions and confirmed with Kovac's indole reagent. Intestinal enterococci were determined on Slanetz-Bartley agar (Lab M, UK) according the standard method SFS-EN-ISO 7899-2 (2000) and confirmed with catalase. Spores of sulphite-reducing clostridia were analysed according the standard SFS-EN 26461-2 (1993) after pretreatment at 75 °C for 15 min on sulphite-iron-agar incubated in anaerobic jars at 37 °C.

Heterotrophic plate count (HPC) was analysed with the spread plate method in two replicates on Reasoner's 2 agar medium (R2A) (Lab M, UK; Reasoner and Geldreich, 1985) and incubated at 22 °C for 3 days. The detection limit was 100 CFU mL^{-1}.

The semi-quantitative detection and identification of thermotolerant *Campylobacter* species were conducted for a total of eight influent and effluent samples out of 20 as described earlier (Hokajärvi et al., 2013) with the modification of using Preston enrichment at 41.5 °C for 21 ± 3 h for 0.1, 1 and 10 mL influent samples and at 37 °C for 44 ± 4 h for 10 and 100 mL effluent samples.

2.4. Viral indicator analyses

Somatic coliphages (host *E. coli* ATCC 13706) and F-specific coliphages (host *E. coli* ATCC 15597) were determined with the double agar technique from a 1 mL sample or its dilution following ISO/DIS 10705-2.2 (1998) and ISO 10705-1 (1995(E)) or with the single layer agar technique from a 10 or 100 mL sample (Grabow and Coubrough, 1986) using the corresponding hosts. The determinations were carried out in two replicates. The method was selected according to assumed number of coliphages in the sample; the detection limits of these methods were 100 PFU in 100 mL^{-1} and

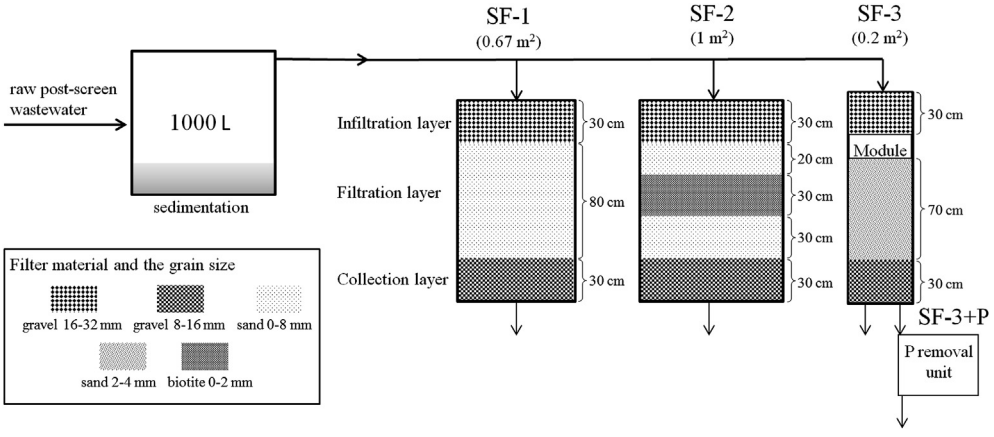

Fig. 1. The experimental setup and structures of studied SFs. The surface areas of SFs are shown in brackets.