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Septic tank discharges as multi-pollutant hotspots in catchments

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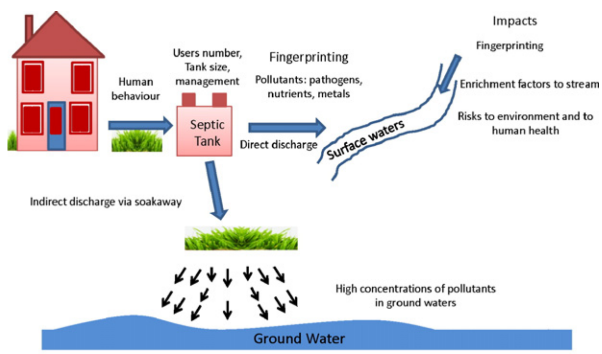
HIGHLIGHTS

- Physicochemical and microbial fingerprinting of effluent discharges are presented.
- STE continues to pose risks to stream ecology, water quality and human health.
- Effluent enrichment factors of NH_4–N, P and Cu were 1486, 261 and 30, respectively.
- Effluent quality was linked with tank condition, management and user number.
- Detection of tryptophan by fluorescence can be used to trace STE contamination.

GRAPHICAL ABSTRACT



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ABSTRACT

Small point sources of pollutants such as septic tanks are recognised as significant contributors to streams' pathogen and nutrient loadings, however there is little data in the UK on which to judge the potential risks that septic tank effluents (STEs) pose to water quality and human health. We present the first comprehensive analysis of STE to help assess multi-pollutant characteristics, management-related risk factors and potential tracers that might be used to identify STE sources. Thirty-two septic tank effluents from residential households located in North East of Scotland were sampled along with adjacent stream waters. Biological, physical, chemical and fluorescence characterisation was coupled with information on system age, design, type of tank, tank management and number of users. Biological characterisation revealed that total coliforms and *Escherichia coli* (*E. coli*) concentration ranges were: 10^3–10^8 and 10^3–10^7 MPN/100 mL, respectively. Physical parameters such as electrical conductivity, turbidity and alkalinity ranged 160–1730 μS/cm, 8–916 NTU and 15–698 mg/L, respectively. Effluent total phosphorus (TP), soluble reactive P (SRP), total nitrogen (TN) and ammonium-N (NH_4–N) concentrations ranged 1–32, <1–26, 11–146 and 2–144 mg/L, respectively. Positive correlations were obtained between phosphorus, sodium, potassium, barium, copper and aluminium. Domestic STE may pose pollution risks particularly for NH_4–N, dissolved P, SRP, copper, dissolved N, and potassium since enrichment factors were >1651, 213, 176, 63, 14 and 8 times that of stream waters, respectively. Fluorescence characterisation revealed the presence of tryptophan peak in the effluent and downstream waters but not detected upstream from the source. Tank condition, management and number of users had influenced effluent quality that can pose a direct risk to stream waters as multiple points of pollutants.

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1. Introduction

Septic tank systems (STS) are the most widely used collection systems for onsite treatment and disposal of domestic wastewater around the world. Their use is particularly common in rural areas where connection to main sewerage network system is not available, or impractical and costly (Dudley and May, 2007). In the UK, only 4% of the population are served by small private treatment works or septic tanks (ST), (DEFRA, 2002), but over one third of dwellings in Ireland (400,000) use them (Gill et al., 2004). Approximately 13% of the Australian population and 25% of households in the United States are served by onsite systems (Dawes and Goonetilleke, 2003; D'Amato et al., 2008). The efficiency of these systems is reflected in the quality of septic tank effluent (STE) and the functioning of the soakaway. STE poses potential risks to human health and aquatic ecosystems if it reaches surface or ground waters without effective treatment (Withers et al., 2014) which depends on tank performance, effluent retention time and the physical, biological and chemical processes inside the tank. Effluent quality also depends on wastewater organic matter content and use of chemicals in the household, which affects bacterial growth and activity in the tank (Brandes, 1978).

Historically, ST were made from bricks or concrete and comprised of one rectangular chamber connected with an inlet pipe (receiving influent from the house) and an outlet pipe (discharging effluent to the soakaway) (May et al., 1996). Septic tanks should be designed to accommodate vertical soil pressure and should be large enough to provide a minimum effluent retention time of 24 h (Seabloom et al., 2005). The primary functions of ST are solids removal from wastewater, accumulation and storage of sludge and scum, breakdown of solid material in an anaerobic digestion process and finally discharge the partially treated effluent to soakaway soil for further treatment (D'Amato et al., 2008). Most STS are capable of treating domestic wastewater effectively at low cost if situated, designed, constructed and maintained appropriately (Environment Alliance PPG4, 2006).

Septic tank effluent is thought to have become to hold negligible or less impact on water quality compared to diffuse pollution (Sharpley et al., 1993; Haygarth et al., 2005). However, domestic wastewater contains a wide variety of potential pollutants including pathogens, faecal bacteria, organic matter (OM), phosphorus (P), nitrogen (N), ammonia (NH_4–N), biochemical oxygen demand (BOD) and suspended solids (SS) as well as pharmaceutical organic compounds and household detergents and chemicals (Gill et al., 2004; Wilhelm et al., 1994; Siegrist et al., 2012) that pose a risk to contaminate fresh waters. Many studies have linked P contamination of surface waters to STE (Bowes et al., 2010; Edwards and Withers, 2008). Bacterial contamination of watercourses from untreated STE is of major concern and poses a risk of disease outbreaks if it contaminates drinking water in nearby water wells (Harris et al., 2013). Lusk et al. (2011) stated that pathogenic bacteria present in STE such as *Escherichia coli* (*E. coli*), *Salmonella* and *Shigella* can cause infections in humans (diarrhoea, nausea, dysentery and hepatitis) in much lower dosage than their actual concentration in STE. Domestic wastewater may contain a number of trace organic chemicals derived from cleaning products, washing detergents and other human activities including caffeine, pharmaceutical compounds, hormones and endocrine disrupting compounds contributing to environmental and human health risks from STE (Kusk et al., 2011).

Although most STs discharge their effluents to soil soakaways for secondary treatment, some STs discharge their effluents and contaminants directly to surface waters or to soakaways that are sited too close to watercourses, (Dudley and May, 2007). Efroymson et al. (2007) declared that the STs that are located within close proximity of watercourses and those with hydraulic failures have direct impacts on water quality. Withers et al. (2011) considered that effluent discharges during low flow periods in summer would have the greatest ecological impact and risk to human health. There is little data on the composition of STE in the UK with which to assess the risk to both water quality and human health. And the variability in effluent quality between different types of tanks and due to effects of management factors is currently poorly known. For example, very few studies have looked across a range of nutrient, metal and microbiological parameters, yet the knowledge of these combinations of contaminants will inform impact, tracing techniques to quantify STE emissions and future control.

In the UK, onsite waste water treatment systems are unregulated and not monitored for performance. In the absence of this knowledge of their true impact, we propose that STE enrichment to freshwaters can pose significant risks at catchment scales acting as small inputs of multiple pollutants. The current study examined the effluent composition of thirty two STE from residential households located in the North East of Scotland. The main hypothesis is that STE compositions indicate they are a major environmental source of physical, chemical and microbial pollution. Knowledge is required on septic tank management and landscape factors that may control effluent composition and potential pollution impact. Therefore, we further hypothesise that 1) STE composition, and hence impact on receiving waters, can be related to tank management factors that may provide risk descriptors and 2) composition factors can be identified to inform development of future environmental tracing methodologies to quantify STE risks.

2. Materials and methods

2.1. Study sites

Thirty two conventional residential septic tank systems serving permanently occupied dwellings located in four rural river catchments in the North East of Scotland were selected for effluent sampling and analysis. Site location, tank management and catchment information is reported in supplementary material (Table S1) and (Fig. S1): Lunan water ($n = 5$), River Dee ($n = 14$), River Don ($n = 8$) and Ythan River ($n = 5$). Selection of sites was based on a survey previously sent to ST users to gain information on their ST system and to acquire permission and agreement to participate in the study. Sites were visually assessed for tank access and for signs of system failure before sampling. Twenty one sites were serviced with individual conventional concrete septic tanks and eleven sites with reinforced fibre glass/polyethylene tank type. Five sites were within 2–10 m from water courses. Three tanks discharged their effluent directly without soakaway secondary treatment to water courses, five discharged the effluent through an undersoil surface soakaway and eventually to streams, and two discharge their effluent to ditches, while others discharged their effluents to surface soil beds or to fields. The ages of the tanks varied from 1 to over 100 years. Management of the tanks also varied; from being emptied yearly to never having been emptied, while some users did not know the history of their tanks. Six of the 32 sites did not use dishwashers. The number of people served by individual ST in this study varied from 1 to 7 people in a household and sampling occurred between February and June 2014.

2.2. Effluent sampling and analyses

Two separate effluent samples were collected from each site: 40 mL was sampled into a sterile vial for microbial, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) characterisation; 1 L was sampled into polyethylene bottle for physical and chemical characterisation. Where possible, stream water samples of the study sites were also collected ($n = 10$). Effluent and water samples were kept in a cold box during transportation to the laboratory then in a cold room at 4 °C until processing. Microbial, BOD and COD analyses were performed within 12 h while processing for physical and chemical analyses were within 36 h. Total viable counts (TVC) of heterotrophic bacteria were performed using a spread plating technique. Serial dilution was made and diluted samples were spread aseptically on top of solidified nutrient