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Contributions of combined sewer overflows and treated effluents to the bacterial load released into a coastal area

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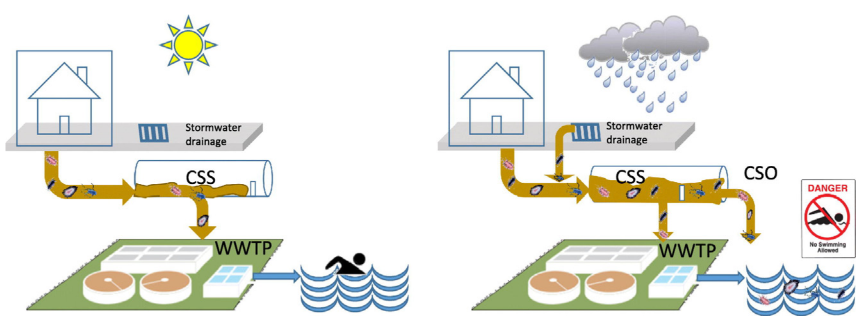
HIGHLIGHTS

- The impact of combined sewer overflows (CSOs) in a coastal area was assessed.
- Microbiological load of CSOs and WWTP effluent was investigated in the study area.
- The study refers to a summer period.
- The contribution of CSOs is 8% in terms of discharged water volume
- CSOs are responsible for >90% of microbial discharged load.

GRAPHICAL ABSTRACT



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ABSTRACT

The impact of combined sewer overflow (CSO) on the receiving water body is an issue of increasing concern, as it may lead to restrictions in the use and destination of the receiving body, such as bathing or recreational area closures, fish and shellfish consumption restrictions, and contamination of drinking water resources. Recent investigations have mainly referred to the occurrence and loads of suspended solids, organic compounds and, in some cases, micropollutants. Attempts have been made to find correlations between the discharged load and the size and characteristics of the catchment area, climate conditions, rainfall duration and intensity.
This study refers to a touristic coastal area in the north-east of Italy, which is characterized by a combined sewer network including 5 CSO outfalls which, in the case of heavy rain events, directly discharge the exceeding water flow rate into channels which, after a short distance, reach the Adriatic Sea. The study analyzed: i) rainfall events during the summer period in 2014 which led to overflow in the different outfalls, ii) the inter- and intra-event variability with regard to *E. coli*, *Enterococci* and conductivity, and iii) the hydraulic and pollutant (*E. coli* and *Enterococci*) loads discharged by the local wastewater treatment plant and by all the CSO outfalls. Finally, it estimated the contribution of each source to the released hydraulic and pollutant loads into the receiving water body. Moreover, it was also found that the modest water volume discharged by all CSO outfalls (only 8% of the total volume discharged by the area) contains >90% of the microbial load.

Abbreviations: ADP, antecedent dry periods; BIO_D, secondary effluent within the WWTP; BY, bypass; CSO, combined sewer overflow; CSS, combined sewer system; EMC, event mean concentration; EMF, event mean flow; MD, combined sewer overflow outfall upstream the wastewater treatment plant; WWTP, wastewater treatment plant.

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1. Introduction

In many urbanized areas, domestic wastewater and rainwater (a mixture that, according to the Council Directive 91/271/EEC, is called *urban wastewater*) are collected and conveyed to the wastewater treatment plant (WWTP) by the same network, known as a combined sewer system (CSS).

Combined sewer overflows (CSOs) may occur in the case of intense rainfall (Barco et al., 2008) and/or periods of melting snow (Madoux-Humery et al., 2013), resulting in a higher water flow rate within the sewer network due to the occasional, but sometimes consistent, contribution of surface runoff, as well as rainfall.

Surface runoff conveyed to the public sewer system may contain suspended solids, organic matter, microorganisms, heavy metals, or pesticides depending on the type, destination and use, width and imperviousness of washing surfaces, rain event frequency and duration, and number of antecedent dry days (Diaz-Fierros et al., 2002; Barco et al., 2008; Galfi et al., 2016b). CSO pollutant concentrations are the result of mixing domestic wastewater and drained stormwater as well as the internal re-suspension of sewer deposits due to flow-induced turbulence. Wastewater and stormwater concentrations as well as their flow rates define the content of the different pollutants (Passerat et al., 2011; Rechenburg et al., 2006).

Receiving water body contaminations by CSOs are intermittent and strictly correlated to the catchment area sewer network (namely pipe diameters and network size), and climate conditions. Their frequency is site-specific and may also vary from one year to another. These overflows are quite often directly released into a surface water body without any kind of treatment (Ouattara et al., 2014).

Due to their pollutant load, this practice can seriously degrade the receptor water quality, causing depletion of oxygen and an increment in suspended solids, nutrients, organic matter, and heavy metals (Barco et al., 2008; Diaz-Fierros et al., 2002; Hanner et al., 2004; Kafi et al., 2008). Moreover, soon after intense rain events, surface water was found to be affected by an increment in the concentrations of *Giardia* and *Cryptosporidium* (Mac Kenzie et al., 1994; Gibson et al., 1998), Norovirus (Campos et al., 2016), and micropollutants (Launay et al., 2016).

This issue is of great concern for water quality control authorities as it could lead to a restriction in the use and destination of the receiving surface body, and consequently, to negative economic impacts. In fact, it could lead to the closure of bathing areas (Burton and Pitt, 2002; Jalliffier-Verne et al., 2016; NYC Global Partners, 2011), restrictions to the consumption of fish and shellfish (Line et al., 2008), and contamination of drinking water resources (McLellan et al., 2007; Galfi et al., 2016b).

It is well known that expensive implementations at large urban WWTPs manage to reduce the residual pollutant load of the treated effluent and thus greatly contribute to improvements in the quality of the receiving surface water body. But these actions cannot attenuate the effects of the short-term disturbances induced by the release of untreated CSOs. This is the case of the catchment area of Brussels, crossed by the Zenne River (Ouattara et al., 2014). The river quality has greatly benefited from the recent upgrade of two large urban WWTPs placed along the river course. However, during intense rain periods, which are quite frequent in the area, a rapid worsening of the microbiological river quality occurs due to untreated CSO releases, resulting in an increment of more than a 2 log factor in the concentrations of *E. coli* and *Enterococci* in the surface water. Similar negative impacts periodically affect other rivers: the Seine (Servais et al., 2007), the Thames (Tryland et al., 2002) and St. Clair River (Ontario, Marsalek et al., 1994). This decrease in quality is much more evident in cases where the receiving receptor is an effluent-dominant river (Buerge et al., 2006).

It was found that *E. coli* concentrations in stormwater runoff may vary from 2 orders of magnitude lower than in raw wastewater (Passerat et al., 2011; Madoux-Humery et al., 2013) to similar wastewater concentrations in the case of septic cross-connections (Sauvé et al., 2012). Moreover, sediment deposits contribute to the occurrence of bacteria in the first phase of intense rainfall (Madoux-Humery et al., 2015) due to their re-suspension induced by the flow turbulence.

Increasing attention has recently been paid to CSO composition and pollutant load. Most studies have investigated overflow occurrence and the temporal-spatial variability of macropollutants (among them Barco et al., 2008; Kafi et al., 2008) as well as micropollutants (mainly organic compounds and pharmaceuticals: Madoux-Humery et al., 2013, 2015; Phillips et al., 2012; Chèvre et al., 2013); the apportionment of the different sources (wastewater, sewer deposit re-suspension and stormwater) in terms of conductivity, total suspended solids (TSS), *E. coli* during a rain event leading to CSO (Madoux-Humery et al., 2015; Passerat et al., 2011), in terms of heavy metals (Diaz-Fierros et al., 2002), and their spatial and temporal variability during different seasons (Madoux-Humery et al., 2015, 2013; Galfi et al., 2016a).

Attempts to quantify and simulate the load of CSOs on surface water have also been recently carried out. Among these, Chèvre et al. (2013) applied the substance flow analysis approach to the town of Lausanne, Switzerland, in order to evaluate how to attenuate the load of pharmaceuticals on the aquatic systems due to CSOs and WWTP effluents, while Pongmala et al. (2015) estimated the dynamics of suspended solids, *E. coli* and the micropollutant carbamazepine in the combined sewer network in a sub-catchment of the large area of Montréal (Canada).

From a regulation point of view, the situation varies from country to country. For instance, U.S.EPA (1993) provided a guidance document regarding the disinfection of CSOs. In particular, it highlights that an acceptable treatment should guarantee a removal of at least 4 log units in bacteria, in detention times of less than the conventional 15–30 min. Canadian Provincial Regulations restrict the frequency of CSO discharges at each outfall location depending on the time of the year, the type of precipitation (rainfall or snowmelt) and the assimilative capacity of the receiving water (Madoux-Humery et al., 2013, 2015). In the United Kingdom, the Urban Pollution Management (UPM) Manual set wet weather standards for protecting river aquatic life, bathing water, shellfish water, amenity use and location of CSO outfalls (Foundation for Water Research, 2012). In Italy, only a few Regions set out guidelines regarding the management of rainwater. For instance, those set out by the Region of Emilia Romagna *suggest* collecting and treating the first 2.5–5 mm of rain which has fallen on an impervious surface (DGR, 2005) while the remainder may be directly discharged. There are no specific prescriptions in cases where the CSO is directly released into the sea.

This study aims to provide new insights in this context, through an assessment of *E. coli* and *Enterococci* loads due to CSOs in a typical Italian coastal area during summertime (the observation period is June–September 2014), and comparing them to those released by the effluent of the local municipal WWTP during the whole observation period (dry + wet days). The aim is to identify which are the most important sources in terms of microbiological pollution in the receiving water body and also to suggest attenuation measures in order to avoid the bathing area closures which have unfortunately occurred on a regular basis over the last few summers.

2. Materials and methods

2.1. The site under study

The study site refers to the area of the municipality of Comacchio (coordinates: 44°42′N 12°11′E), situated in the eastern side of the Po Valley, north-east Italy. The area is adjacent to a lagoon (Comacchio Lagoon) and is characterized by an altitude of 1 m over the sea level. The study catchment basin has an extension of 850 ha; the land use is 72% residential, 12% institutional and commercial, 15% open lands and 1% industrial. The area can be classified as a residential centre; its impervious