Journal of Hydrology 554 (2017) 397–405

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Micropollutants throughout an integrated urban drainage model: Sensitivity and uncertainty analysis

Giorgio Mannina *, Alida Cosenza, Gaspare Viviani

Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali, Università di Palermo, Viale delle Scienze, 90128 Palermo, Italy

ARTICLE INFO

Article history:
Received 20 July 2017
Received in revised form 12 September 2017
Accepted 13 September 2017
Available online 18 September 2017
This manuscript was handled by G. Syme, Editor-in-Chief

Keywords:
Contaminants of emerging concerns
Mathematical modelling
Monte Carlo simulations
Sensitivity analysis
Urban water quality

ABSTRACT

The paper presents the sensitivity and uncertainty analysis of an integrated urban drainage model which includes micropollutants. Specifically, a bespoke integrated model developed in previous studies has been modified in order to include the micropollutant assessment (namely, sulfamethoxazole – SMX). The model takes into account also the interactions between the three components of the system: sewer system (SS), wastewater treatment plant (WWTP) and receiving water body (RWB).

The analysis has been applied to an experimental catchment nearby Palermo (Italy): the Nocella catchment. Overall, five scenarios, each characterized by different uncertainty combinations of sub-systems (i.e., SS, WWTP and RWB), have been considered applying, for the sensitivity analysis, the Extended-FAST method in order to select the key factors affecting the RWB quality and to design a reliable/useful experimental campaign.

Results have demonstrated that sensitivity analysis is a powerful tool for increasing operator confidence in the modelling results. The approach adopted here can be used for blocking some non-identifiable factors, thus wisely modifying the structure of the model and reducing the related uncertainty. The model factors related to the SS have been found to be the most relevant factors affecting the SMX modeling in the RWB when all model factors (scenario 1) or model factors of SS (scenarios 2 and 3) are varied. If the only factors related to the WWTP are changed (scenarios 4 and 5), the SMX concentration in the RWB is mainly influenced (till to 95% influence of the total variance for $S_{SMX,max}$) by the aerobic sorption coefficient.

A progressive uncertainty reduction from the upstream to downstream was found for the soluble fraction of SMX in the RWB.

1. Introduction

In the last three decades, scientific research focused on preservation of water environment and on the impact of urban areas pollutants of natural water bodies especially in terms of macropollutants (carbon, nitrogen, phosphorus). However, the Water protection legislations (e.g. the EU Water Framework Directive (EC, 2000) and the Environmental Quality Standard Directive (EC, 2008) also require the reduction of a range of micropollutants (MP), i.e. substances such as drugs, pharmaceuticals, personal care products, biocides, etc.

These substances are characterized of being persistent in the environment, toxic and bioaccumulative (EPA, 2013). Indeed, despite they are not naturally contained in the environment they have been found in some water bodies (Loos et al., 2013). MPs can lead to significant risk on the environment and human health. Several studies have demonstrated adverse effects of MP on the aquatic life (Coe et al., 2008; Lange et al., 2009). Therefore, the reduction of the discharged load and/or the elimination of these compounds inside the wastewater treatment plant (WWTP) before being discharged in the aquatic environment is an important issue with regard to the quality (Huerta-Fontela et al., 2010; McCall et al., 2016; Ramin et al., 2016).

In this context mathematical modelling can represent an useful tool to assess the MP load discharged in the environment as well as to develop strategies aimed at controlling MP pollution.

With this regard, researches have demonstrated the importance of integrated analysis, involving both quantity and quality aspects. The integrated analysis has the advantage of taking into account the interactions between two or more physical systems, i.e. sewer system (SS), WWTP and receiving water body (RWB) (Rauch et al., 2002; Willems and Berlamont, 2002; Freni et al., 2009a,b). An integrated urban drainage model (IUDM) is therefore composed of submodels able to simulate the key processes of each system and the interactions among them. Therefore, IUDMs are often complex and

---

* Corresponding author.
E-mail address: giorgio.mannina@unipa.it (G. Mannina).

https://doi.org/10.1016/j.jhydrol.2017.09.026

involve tens of model parameters and model variables. Thus, the use of such complex models requires a robust database for their calibration and validation before being confidence on the modelled results (Bach et al., 2014).

During the last years, IUDMs have been made further complex by introducing the MP fate and transport (Bach et al., 2014).

Recently, Vezzaro et al. (2012) have introduced an integrated model, combining MP source characterization with dynamic modelling of runoff quality and stormwater treatment. However, authors have calibrated only the hydraulic sub-models due to the MP data lacking. Therefore, modeller cannot completely be confident with the results.

In view of providing results as more reliable as possible, modeller should apply a parsimonious approaches for integrated complex model and/or opportunely collect useful data to be adopted for model calibration/validation.

However, the collection of monitoring data is affected by significant limitations (Freni and Mannina, 2012; Ledin et al., 2013). These limitations can be technical and economical, as the data collection requires huge human and economic resources. Moreover, difficulties of collecting measurements carried out at the watershed outlet are often exhibited in literature (Freni and Mannina, 2012; Vezzaro et al., 2014; Freni and Mannina, 2010). Therefore, the challenge of improving the existing databases is a common practice of dedicated research projects. These difficulties in the data acquiring are amplified for MPs since they are commonly found in low concentrations (in the range of ng/l-mg/l) which are difficult to measure (Vezzaro et al., 2014).

In this context, sensitivity analysis (SA) can represent a very powerful tool to provide useful information required to design an effective (both in economical and usefulness terms) sampling campaign. Indeed, SA provides information about how the model output variation can be apportioned to the input factors variation. Therefore, SA allows the selection of the key factors mostly affecting the model results. Among the SA methods, global sensitivity analysis (GSA) has several advantages. GSA can help modeller to identify important input factors (factors prioritisation) as well as non-influential input factors (factors fixing) (Saltelli et al., 2005). Moreover, some GSA methods are also able to quantify the model variance contribution due to the synergistic or co-operative effect among factors (Saltelli et al., 2005, Cosenza et al., 2013). Therefore, in the IUDM context GSA can provide information about the relationships among the different sub-systems (i.e., SS, WWTP and RWB).

GSA should also provide an answer to the milestone for an effective monitoring campaign designing: i. What are the most significant/important factors contributing to the uncertainty for IUDM? ii. How does the uncertainty related to the data lacking affect the RWB results?

Thus, this paper presents an integrated water quality urban drainage model that is able to model the sulfamethoxazole (SMX) fate throughout each component of the integrated system (SS, WWTP and RWB).

In order to evaluate the effect of the uncertain of model parameters on the RWB quality, the GSA has been applied. More precisely, five scenarios have been analysed and compared by adopting Extended-FAST method, each considering a set of model factors as unknown. Furthermore, the he uncertainty propagation from the SS to the RWB has been evaluated.

2. Material and methods

2.1. The integrated urban drainage model

The system was modelled employing a bespoke integrated model developed during previous studies (Mannina et al., 2006). The integrated model simulates the main phenomena taking place in the SS, WWTP and RWB during both dry and wet weather period. The model is made up of three sub-models, each divided into a quantity and quality module for the simulations of the hydrographs and pollutographs, respectively (Fig. 1). More precisely, the integrated model is divided into: (i) the rainfall-runoff and flow propagation sub-model, which evaluates the qualitative-quantitative features of the storm water; (ii) the WWTP sub-model, which is representative of the treatment processes; (iii) the RWB sub-model, which simulates the pollution transformations inside the RWB (Fig. 1).

The integrated model proposed by Mannina et al. (2006) has been modified in order to include the SMX modelling in each sub-model according to previous literature (among others, Vezzaro et al., 2010, 2012; Plósz et al., 2012). A description of each sub-model will be provided below; further details about the model can be found in literature (Mannina et al., 2006; Mannina and Viviani, 2009, 2010a,b,c).

2.1.1. SS sub-model

The SS sub-model simulates the quality–quantity features of rain water during a storm event, which is applied to combined sewer systems receiving both domestic sewage and stormwater. Specifically, the quantity module evaluates the net rainfall from the measured hyetograph by adopting the loss function that takes into account the surface storage and soil infiltration. The net rainfall is then used to simulate the net rainfall–runoff transformation process and the flow propagation. This latter is evaluated by means of a cascade of two linear reservoirs in series and a linear channel. The linear channel allows to split the hydraulic phenomena in the catchment from those in the SS.

Regarding the quality module, the build-up and the wash-off phenomena on the catchment surfaces are modelled coupled with the sediment deposition and erosion processes inside the sewer. The build-up on the catchment surfaces is modelled by using the exponential function as proposed by Alley and Smith (1981). The solid wash-off that occurs during the storm event was modelled according to Jewell and Adrian (1978). The transport equation proposed by Parchure and Mehta (1985) coupled to the bed sediment structures hypothesized by Skipworth et al. (1999) were used to simulate the sediment erosion rate in the SS.

The SMX concentration inside the SS has been modelled by using two state variables: dissolved (S_{SMX}) and particulate (X_{SMX}). In Table 1 the transformation processes and the rates for SMX concentration in the SS are summarized. The SS sub-model applied here has the advantage to consider both SMX sorption and biotransformation in sewer networks, mostly omitted in regional model-based assessments (e.g. Ort et al., 2009) (Table 1). Further-

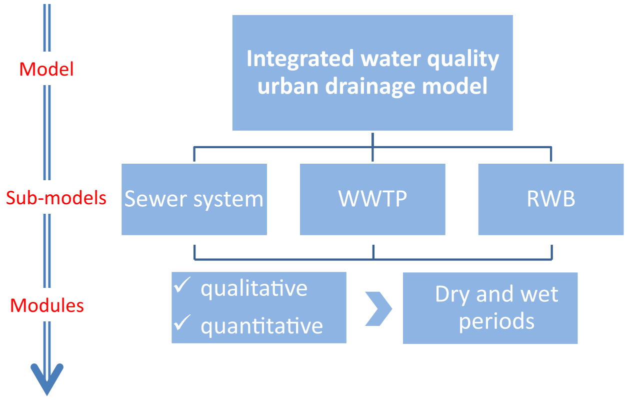

Fig. 1. Schematic overview of the integrated model.