An automatic warning system for faecal contamination in urban recreational lake

Un système d'alerte automatique des contaminations fécales dans les plans d'eau en milieu urbain

Yi Hong[1*], Frédéric Soulignac[2], Adélaïde Roguet[3], Francesco Piccioni[1], Philippe Dubois[1], Bruno J. Lemaire[1], Françoise Lucas[1] Brigitte Vinçon-Leite[1]

[1] LEESU, UMR MA 102, Ecole des Ponts ParisTech, AgroParisTech, UPEC, UPE, 77420 Champs-sur-Marne, France
[2] ENAC, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
[3] School of Freshwater Sciences, University of Wisconsin-Milwaukee, Milwaukee, WI 53204, USA

* yi.hong@enpc.fr

RÉSUMÉ

La demande de loisirs aquatiques et de baignade en eau libre est actuellement en forte croissance, en particulier dans les régions urbanisées. En Île de France, la perspective des Jeux Olympiques de 2024 renforce la demande de prévision des contaminations fécales dans les plans d'eau et de conformité à la réglementation. Ce travail porte sur le développement d'un système de surveillance et prévision, consultable sur ordinateur ou Smartphone, qui renseigne les gestionnaires et les usagers de sites de baignade en eau douce sur la dynamique d'une bactérie indicatrice de contamination fécale *Escherichia coli* (*E. coli*) dans leur plan d'eau. Afin de simuler le transport et l'évolution de la biomasse d'*E. coli* du bassin-versant urbain au milieu récepteur, une approche de modélisation intégrée couplant le modèle SWMM et le modèle Delft-3D a été développée. Les paramètres sont calibrés et validés avec les mesures *in-situ* de débits et de concentrations d'*E. coli*. Des scripts en Python, C++, Matlab, SQL, HTML, Javascript et CSS ont été développés pour automatiser ce système qui comprend: (1) l'acquisition en continu de prévisions météorologiques; (2) le transfert, le stockage et la validation automatique des données acquises ; (3) la modélisation et la prévision de la distribution d'*E. coli*; (4) l'affichage ergonomique de ces résultats sur une plateforme web, accessible sur ordinateur ou Smartphone.

ABSTRACT

In recent years, recreational waterbodies are increasingly favoured in urban areas. This worldwide trend requires minimum standards for achieving and maintaining high water quality at all times to ensure the protection of public health. This study develops an automatic monitoring and modelling system, which is accessible on a website or Smartphones, for warning stakeholders and public about the dynamics of a faecal indicator bacteria *Escherichia coli* (*E. coli*) in the lake. In order to simulate the transport and fate of *E. coli* from the urban catchment to the receiving lake, an integrated modelling approach is proposed by linking the SWMM and Delft-3D models. Model parameters are calibrated and validated with *in-situ* measurements of the flow rate and *E. coli* concentrations. Python, C++, Matlab, SQL, HTML, Javascript and CSS scripts are developed for automating the system procedures such as: (1) continuous acquisition of the meteorological forecast; (2) automatic data transfer, storage and validation; (3) modelling and prevision of *E. coli* distribution; and (4) design and display of the results on the website, accessible from computers or Smartphones.

KEYWORDS

Escherichia coli propagation; Integrated monitoring and modelling; Recreational lake; Urban stormwater drainage; Warning system;

1 INTRODUCTION

Recreational waterbodies are becoming increasingly favoured in urban areas worldwide. However, watersports enthusiasts can be exposed to various pathogenic microorganisms, which may cause public health risks (Fewtrell and Kay, 2015). Fecal coliform bacteria associated with stormwater discharges has been considered as one of the major sources of these microbiological pollutants (Marsalek and Rochfort, 2004). During the rainfall events, such contaminants are entrained by urban stormwater runoffs from separated sewers to waterbodies, causing the degradation of bathing water quality.

Escherichia coli (*E. coli*) has been commonly recognized as the best biological indicator for public health protection (Edberg, Rice, et al., 2000). According to literature, the typical levels of this indicator in stormwater greatly exceed the existing recreational water guidelines (Marsalek and Rochfort, 2004). Therefore, it is essential to assess the impacts of urban stormwater drainage on the spatial distribution and dynamics of the *E. coli* in receiving waterbodies, in order to determine the healthy limits for aquatic activities as well as drinking water intakes.

Due to the complexity of natural processes in water bodies, physically-based and spatially distributed models are valuable tools for a better understanding of the interactions between variables driving fecal contaminations, as well as for helping stakeholders to determine their management strategies. However, traditional *in-situ* measurements have too limited temporal and spatial resolution to make such a numerical model reliable. Efforts must be made to use innovative tools to overcome these limitations. Therefore, this study aims to develop a novel real-time warning system, capable of predicting the dynamics of *E. coli* in the urban catchment and the receiving lake, which is accessible on a website or Smartphones.

2 MATERIALS AND METHODS

2.1 Study site

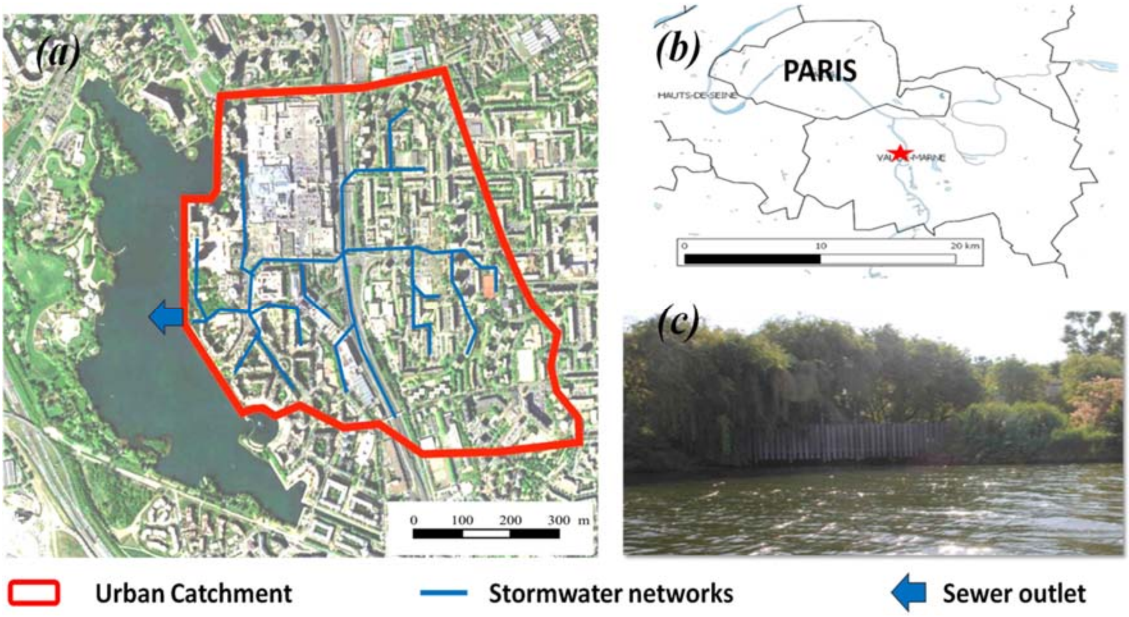

Figure 1. Study area at South-eastern Paris, France. (a) Urban catchment, recreational lake, and stormwater sewer networks; (b) Site location; (c) Sewer outlet.

The study area is located at South-eastern Paris (Creteil, Val-de-Marne, France), consisting of a recreational urban shallow lake, Lake Creteil; and an urban catchment, where a single stormwater outlet discharges into the lake (Figure 1). Lake Creteil is a 42 ha sand-pit lake, which is mainly supplied by alluvial ground water from the nearby Seine and Marne river. The total surface of this urban catchment is 95 ha, with a eastern section higher than the western side.

2.2 Automatic warning system

The automatic warning system consists of four sequential steps: (1) continuous acquisition of the *in-situ* measurements of various sensors and meteorological forecast; (2) automatic data transfer, storage and validation; (3) simulation of the *E. coli* distribution with the integrated modelling approach; and (4) design and display of the results on the website, accessible from computers or Smartphones. In order to automate the system procedures, scripts written in different computer languages such as Python, C++, Matlab, SQL, HTML, Javascript and CSS are developed.

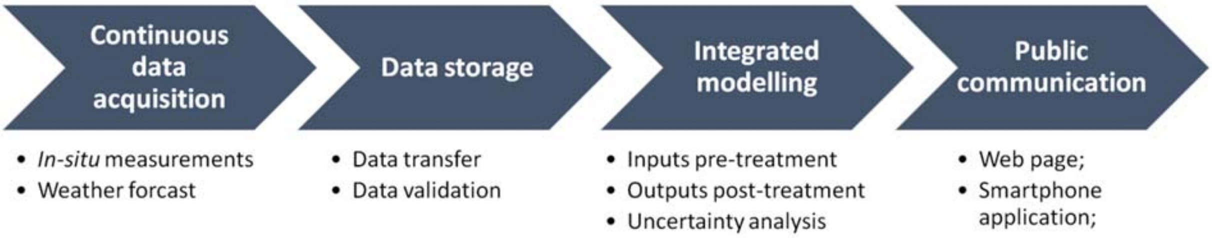

Figure 2. Scheme of the automatic warning system.

In the integrated modelling approach, SWMM model *(Rossman, 2010)* is used for the modelling of rainfall-runoff, sewer networks, generation and transport of *E. coli* in the studied urban catchment.The 3D-model Delft3D-FLOW-WAQ *(Deltares, 2016)* is used to simulate the hydrodynamics and *E. coli* transport in Lake Creteil.

In SWMM model, the total catchment is divided into 21 sub-catchments according to the administrative divisions of residential, commercial and industrial zones. The surface runoff of each sub-catchment is simulated as non-linear reservoirs and given by the Manning's equation. The build-up and washoff processes of *E. coli* are calculated by using exponential equations. On the other hand, water flow in sewer networks is computed by the 1D kinematic wave equations and solved by the finite-difference scheme. *E. coli* routing within conduits assumes that the conduit behaves as continuously stirred tank reactor (CSTR).

In Delft3D-FLOW-WAQ model, the model solves the unsteady shallow water equations in three dimensions. The dynamics of *E. coli* are calculated by advection-diffusion-mortality equations, where the mortality of *E. coli* can be enhanced by temperature, and solar radiation. In the 3D-model, the horizontal surface of the lake is meshed with 981 Cartesian cells of 20 m × 20 m, while the vertical direction of the model is divided into 18 layers of 33 cm.

3 RESULTS AND DISCUSSION

Comparing the simulated discharges and *E. coli* concentrations with the continuous measurements of water flow and the measured event mean concentration of *E. coli*, respectively, the parameters of SWMM model is calibrated for the rainfall event of Oct. 14th, 2013, and validated for the events of Oct. 20th and Nov. 3rd, 2013 (Hong, Li, et al., 2019). Moreover, using the calibrated hydrodynamic parameters in previous studies (Soulignac, Vinçon-Leite, et al., 2017) and the default values of *E. coli* parameters of the Delft3D model, the spatial and temporal dynamics of *E. coli* in the receiving water body after each rainfall event can be simulated. As an example, the figure 3 presents the distribution of *E. coli* in Lake Creteil, after 1h, 3h, 6h, 12h and 24h of the rainfall event of 14th Oct. 2013. These results can be displayed on the website for public communications.

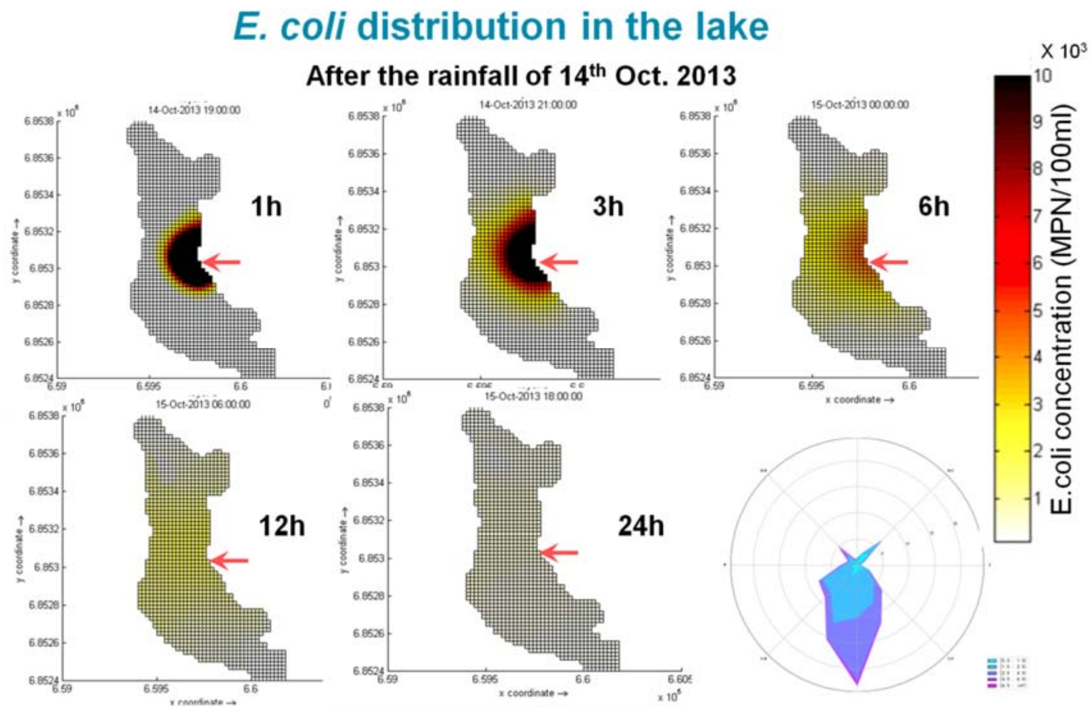

Figure 3. The distribution of *E. coli* in Lake Creteil after the rainfall event of the 14th Oct. 2013.

4 CONCLUSION AND PERSPECTIVE

In this study, we developped an automatic warning system, for predicting the spatial and temporal dynamics of fecal contamination caused by stormwater discharges in an urban recreational lake. This integrated approach yielded promising results in reproducing the dynamics of *E. coli*. This system could be used as a decision-making tool for urban water managers to decide weather the recreational activities can be authorized or prohibited for publics. Further studies will focus on the development of automatic parameter optimisation and uncertainty analysis, as well as on the assessment of long-term impacts and management scenarios.

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