A chemical fate model for screening impacts from wet-weather discharges on Danish streams

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Un modèle de prédication chimique pour détecter les impacts des déversoirs d'orage sur les cours d'eau danois

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RÉSUMÉ

L'évaluation des impacts négatifs des micropolluants provenant des rejets urbains par temps de pluie (rejets par les déversoirs d'orage et eaux de ruissellement) requiert des efforts longs et exigeants en termes de supervision et de modélisation. Nous présentons un outil de sélection pour faciliter l'évaluation de l'impact, en utilisant les sources de données publiques disponibles. Le modèle est basé sur des bilans massiques simples (la dilution) et inclut six processus de devenir chimique. Le modèle estime le devenir de 39 micropolluants différents dans 1791 cours d'eau danois. Ces cours d'eau ont été examinés pour déterminer s'ils dépassaient les normes de qualité environnementale. Une analyse de sensibilité et une analyse d'incertitude ont été réalisées pour étudier l'impact des différentes sources d'incertitude sur les résultats. Les résultats du modèle ont montré qu'une fraction importante des cours d'eau (>40%) pourrait dépasser les concentrations maximales autorisées pour certains métaux lourds (Cu, Zn) et les hydrocarbures aromatiques polycycliques en raison des rejets par temps de pluie. Compte tenu de la structure simple de l'approche proposée, et de l'utilisation de données ouvertes, l'approche proposée peut facilement être appliquée dans d'autres pays et régions. Cette approche pourrait permettre de prioriser les ressources souvent limitées pour réduire les impacts environnementaux négatifs des rejets urbains par temps de pluie sur l'environnement naturel de l'eau.

ABSTRACT

Assessing the impacts of micropollutants released via urban wet weather discharges (combined sewer overflows and separate storm sewers) often requires resource-intensive monitoring and modelling activities. We present a screening tool to facilitate impact assessment and prioritize pollution reduction investments, utilizing public available data sources. The model is based on simple mass balances (i.e. dilution) and it includes six chemical fate processes for the pollutant transport in the streams. The model estimates the fate of 39 micropollutants in 1791 Danish streams. These streams were screened for a potential exceedance of Environmental Quality Standards. Sensitivity analysis and uncertainty analysis were performed to investigate the impact of the different sources of uncertainty on the results and importance of the different fate processes. The model outcomes indicates that > 40% streams potentially exceed the Maximum Allowed Concentrations for some heavy metals (Cu, Zn) and PAHs as consequence of wet-weather discharges. Considering the simple structure of the proposed approach, and the use of open data, the proposed approach can be transferred to other countries and regions. This will eventually help to prioritize the often limited resources for reducing the environmental impacts of urban wet weather discharges on the natural water environment.

KEYWORDS

Chemical Risk Assessment, Combined Sewer Overflows, Micropollutants, Stormwater, Uncertainties

1 INTRODUCTION

Pollutants from wet-weather discharges (WWD, comprising combined sewer overflows and separate storm sewers outlets) negatively affect the chemical and ecological status of natural water streams. Wet-weather discharges contain a wide range of micropollutants (MP - Mutzner et al., 2022), causing acute and chronic impacts. The magnitude of these impacts depend not only on the composition of the discharged water, but also on the characteristics (dimensions, sensitivity, other stressors, etc.) of the receiving water body (RWB).

The holistic perspective, which takes the RWB into consideration when regulating wet-weather discharges, has long been acknowledged by European and national regulations. In Denmark, for example, WWD discharge permits granted by municipalities should consider the sensitivity of the receiving water body (e.g. by defining the acceptable yearly frequency of discharge events). In practice, however, authorities tend to fall back to standardized limits, disconnected from the actual condition of the system (Jensen et al., 2020).

The implementation of holistic approaches in WWD regulation is hampered by (a) lack of knowledge on the pollutant levels in WWD (e.g. concentrations, pollutants, inter- and intra- event variability), and (b) the difficulties in assessing the WWD impacts on the river (including the application of existing modelling tools). A thorough impact assessment would require extensive resources for monitoring campaigns, data acquisition, and calibration of river models. Considering that in a relatively small country like Denmark there are about 20,000 WWD structures, there is a need for easily applicable assessment tools, relying on existing data.

This study aims at developing a screening tool to assess the acute impacts of wet-weather discharges on the chemical status (i.e. on micropollutant levels) in Danish river water bodies by using open-access data. These include physical RWB data (e.g. flow data), modelled WWD discharges (flow) and literature measurements on WWD pollution levels . The developed tools provides an initial screening of river stretches that are more likely to be negatively affected by WWD, highlighting the areas where monitoring resources should prioritized.

2 MATERIAL AND METHODS

2.1 Data availability

The chosen approach utilizes easily accessible data, which can be retrieved from public databases and publications and include data on:

- River flow: the Geological Survey of Denmark and Greenland runs a model of the entire water cycle across the country (hip.dataforsyningen.dk). Simulated flow data Q [m^3/s] for all the Danish river are available for the period 1990-2019 (at monthly resolution), with a spatial resolution of 100-500 m (for 1791 streams).
- Lake dimensions: geographic information on lakes are available in the hydroLAKES database (www.hydrosheds.org/products/hydrolakes)
- WWD quantity: the Danish Environmental Agency provides a record with location and discharges of the almost 4,500 combined sewer overflows and 15,000 separate storm sewer outlets across the country (arealinformation.miljoeportal.dk). Data for each discharge are provided as yearly cumulative volumes, with the greater fraction of volumes being modelled, and a minor fraction being measured.
- WWD quality: the MP distributions from the recent study by Mutzner et al., (2022) were utilized to define the pollution levels.

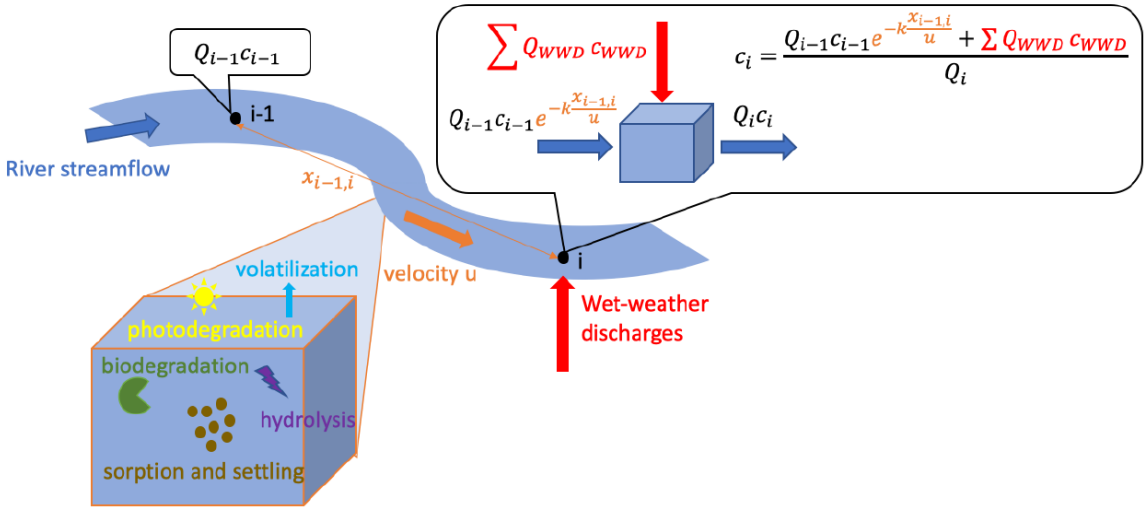

Figure 1 . Conceptual scheme of the applied modelling approach

2.2 Chemical fate model

The applied model expands the dilution model presented in Vezzaro et al. (2022) with chemical fate process (Figure 1): partitioning, settling, volatilization, hydrolysis, photolysis and biodegradation. These were simulated as first-order processes, only affecting the dissolved phase (and only settling affecting the particulate phase). A total of 39 MPs were analysed, chosen among those listed in Mutzner et al. (2022), having been detected in over 50% of the monitoring sites and having a risk quotient against Environmental Quality Standards (EQS) higher than 1.

3 RESULTS

3.1 Behaviour of the chemical fate model

The sensitivity analysis of the developed model highlighted that the half-lives of the majority of the investigated substance and processes are significantly bigger than the residence time in Danish streams. Therefore, partitioning has been highlighted has the most important process in the risk estimation (and obviously for those MP whose EQS is defined for the bioavailable fraction). Also, Danish lakes, having great residence times, acted as MP sink, i.e. lake effluents are not affected by MP emissions from WWDs.

A Monte-Carlo analysis, performed on selected MPs (Pb and Benzo[b]uoranthene) to quantify the uncertainty linked to the model parameters, showed that the estimated risk (expressed as number of stream nodes exceeding EQS) was comparable to the results obtained by using a deterministic model and the distribution values from Mutzner et al. (2022). This shows that the model results (as those shown in Figure 2) can be obtained with a relatively small computational burden.

3.2 WWD impacts on Danish streams

Figure 2 shows the results of the risk assessment performed across all the Danish streams. An important fraction of the streams (>40%) exceeds the EQS for some metals (Cu, Zn) and PAHs when a median value of MP pollution in UWD is employed. Figure 3 shows the spatial distribution of the simulated streams, along with the chemical risk in a worst-case scenario (90% percentile MP concentration in UWD). These results highlights areas where resources for monitoring and modelling river quality should be prioritized.

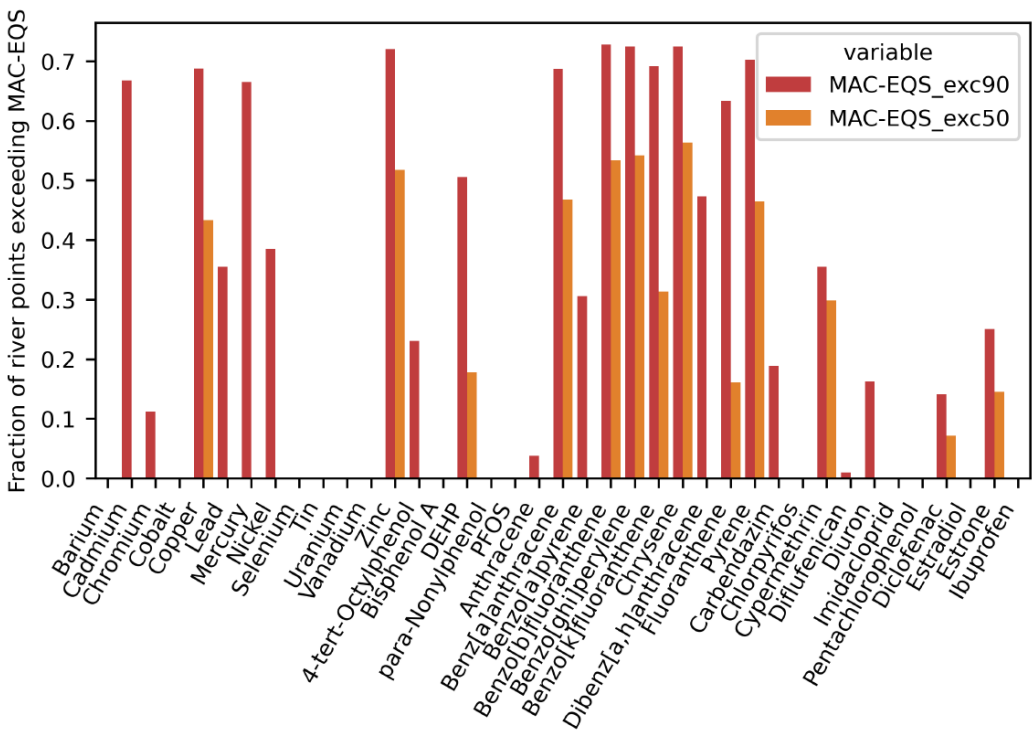

Figure 2 . Fraction of modelled stream nodes exceeding the Maximum Allowed Concentration (MAC) EQS, calculated by using median (orange) and 90% percentile (red) MP concentrations in WWD.

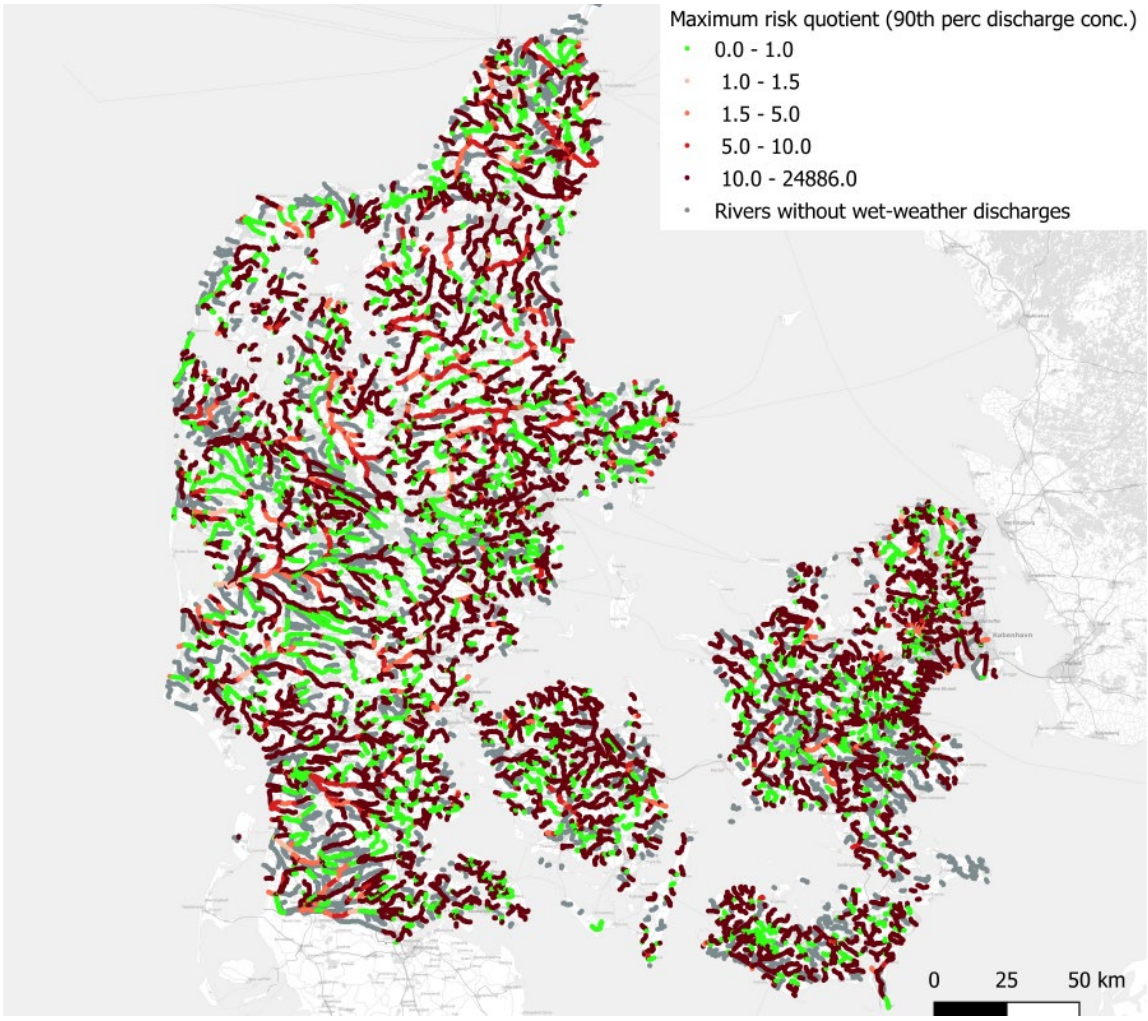

Figure 3 . Simulated maximum Risk Quotient (RQ) for Danish streams due to WWD discharges (90% percentile MP concentration, according to the principle “one out, all out”

4 CONCLUSIONS AND FUTURE OUTLOOK

This study presents a screening tool that allows urban water managers and regulator to prioritize RWB stretches which might be negatively affected by wet-weather discharges. The model includes several fate processes, needed to consider the wide range of MPs found in WWDs. Sensitivity analysis and uncertainty analysis, however, suggests that the risk assessment only requires few processes (partitioning) and a limited number of simulations (i.e. no need for heavy simulations when MP distributions are known).

The presented study utilized public available data at the Danish level. However, similar data (although at a lower resolution) can be retrieved in several countries (e.g. Quaranta et al., 2022). Therefore, the presented screening approach can become an effective tools for prioritizing resources and reducing WWD negative impacts across the entire European continent.

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