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Parameterisation and validation of the CleanCityCover tool to assess source areas of urban diffuse pollution for case study areas in Aarhus, Denmark

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Abstract

Diffuse pollution from polluted urban surfaces and transported with stormwater runoff into surface waters remains a significant challenge towards achieving zero pollution from cities. Often it appears to be not clear where what kind of pollution actually originated. We therefore adopted a pollution source area approach to develop a tool named CleanCityCover, which identifies critical source areas of urban diffuse pollution. The tool was parameterised for four study areas in Aarhus for three pollution types – dry deposition, pollution due to traffic and metal roofs. The CleanCityCover is a web-based, interactive tool displaying the spatial patterns of different pollution types, summary of annual runoff quality, results of functional connectivity analysis and a pollutant ranking summary. The tool is validated for heavy metal (zinc, copper and lead) concentrations from the runoff of three of the four study areas in Aarhus. A reasonable validation was achieved at the three study areas with correlation coefficient varying from 0.57 to 0.92.

Highlights

- CleanCityCover is an identification tool for critical urban source areas of diffuse pollution.
- The tool was parameterised for four study areas in Aarhus, Denmark.
- The tool was validated for heavy metal concentrations in runoff with monitored data.

Introduction

Revised European Union Waste Water Treatment Directive (UWWTD, 2022) emphasis the need to improve the management of storm water in cities by reducing the risk of pollution due to heavy rainfall-runoff events. Tackling the diffuse pollution in surface and groundwater bodies due to urban runoff requires a source area approach. Paton and Haacke (2021) categorised the sources of diffuse pollution according to their intrinsic patterns of pollution source areas considering their spatial and temporal variations. It was shown that there is a need to assess these source areas in terms of their structural and functional connectivity of pollutant transfer to enable an adequate management of urban surface pollution. The term structural connectivity refers to the physical connection between polluted urban surfaces and the functional connectivity describes the dynamic processes within these structurally connected surfaces that impact the transport and fluxes of water and particles between source and outlet (Wainwright et al., 2011). In this study, we adapted this holistic approach to develop a diffuse pollution identification tool for urban sealed surfaces called CleanCityCover. The purpose of the tool is the identification of particularly contaminated urban areas contributing the largest amount or the highest toxicity levels to diffuse pollution. The following presents the components of the tool, the parameterisation and validation of the tool for case study areas in Aarhus, Denmark.

Methodology

Components of the tool

CleanCityCover is a web-based interactive application developed using the Shiny package in R. It consists of three components: a multi-facet database (highlighted in blue in Figure 1), a SWMM modelling component for structural and functional connectivity analysis (highlighted in orange) and a shiny app interface (highlighted in green). The database contains meteorological information on rainstorm characteristics, high-resolution geodata detailing the surface types down to the building scale, and a pollution database with information on urban pollution build-up and transfer such as wet and dry deposition, street and traffic pollution, abrasive pollution from metal roofs and many more.

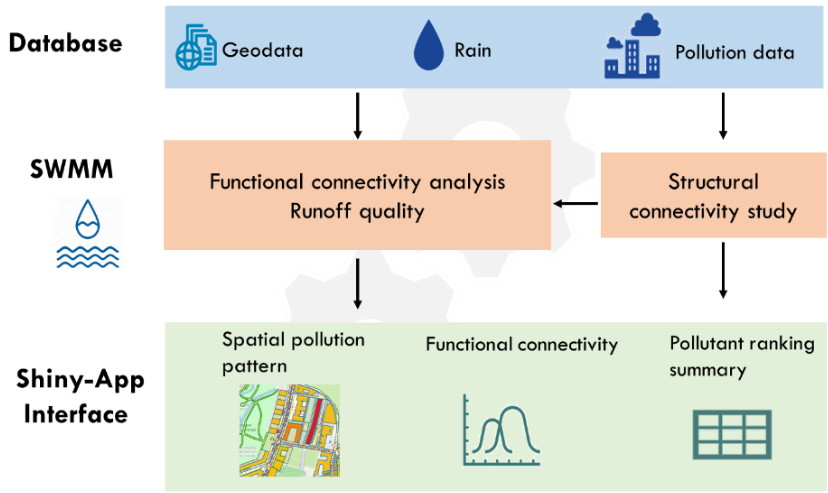

Figure **1.** Three components of the tool CleanCityCover: Database, SWMM modelling and Shiny App interface.

Functioning of CleanCityCover

The functional connectivity, i.e. the potential to transfer pollutants with overland flow, is assessed by computing the overland flow from a hypothetical street surface in SWMM using one-minute rainfall over a time period of ten years. In a next step, three years (dry, wet and flashy) are identified and selected to assess annual pollution loads.

Urban diffuse pollution data collected from a large range of field studies (Liu et al., 2016; Revitt et al., 2022; Galster and Helmreich, 2022) are used to parameterise the spatial pollution pattern of different pollution types for associated surface covers (streets, pavements, squares, roofs) on the city scale. The structural connectivity of the source areas to the drainage system or groundwater is evaluated and the runoff quality is computed in SWMM for the three selected years using the information on pollutant spatial patterns, build-up and wash-off parameters after Tu and Smith (2018). Finally, the priority ranking of areas and pollutants is calculated by considering the annual amount of individual pollutants in the runoff and their toxicity. Results of structural and functional analysis and ranking of diffuse pollution are then visualised in a web-based interface of Shiny app (Figure 2).

The tool CleanCityCover is developed as part of the 2020 project EU Horizon project WATERUN, which focuses on developing tools to achieve zero water pollution in cities.

Case study

The tool was parameterised for four sub-areas (catchment size ranging from 0.5ha to 17.5ha) in Aarhus, Denmark for three pollution types- dry deposition, pollution due to traffic, and metal roofs. The tool was validated in two of these sub-areas for total nitrogen, dissolved zinc and copper concentrations. An extensive runoff sampling campaign (Table 1) was carried out from May 2024 to September 2024 using automatic grab sampling, which is initiated when a rain event exceeded 2.2 mm in 30min. This threshold is based on average rain intensity in Aarhus. Water samples were extracted by 12v pumps at different time delay and were retrieved within 24 hours and brought back to the laboratory for filtration (0.45µm CA+GF syringe filter). The filtered samples are analysed by Inductively Coupled Plasma Spectroscopy.

Table 1. Summary of runoff sampling and heavy metal measurement conducted in the year 2024 at three study areas in Aarhus, Denmark.

Study areas	Location	Catchment size (ha)	Runoff quality parameters used for validation	Number of runoff events
Area 1	Tulip-grunden wet pond, 8220 Braband	2.2	Zinc, Copper, Total nitrogen	9
Area 3	Risvangen, 8200 Aarhus	0.5	Zinc, Copper, Total nitrogen	6

Results and discussion

Parametrisation of CleanCityCover for study areas in Aarhus, Denmark

A parameterisation of the CleanCityCover tool for a residential study area in Aarhus is presented in Figure 2. It consists of an input panel on the left and five tabs on the top with the tab ‘Base map’ displayed by default. The input panel contains three fields – ‘year’, ‘sub-area’ and ‘pollution type’ to be selected by the user. The user can choose between a wet, dry and flashy year and can select one of the three sub-areas. The tab ‘Base map’ to the right of the panel comprises an overview map of the city with the four sub-areas. Clicking on the ‘Simulate’ button, the tab ‘Pollution results’ opens up with an interactive map showing the spatial pattern of the selected pollution type with a summary of the simulated annual load of each selected pollution type originating from that area for the selected year (Figure 2, right). The tab ‘Runoff’ shows the results of the functional connectivity analysis. The tab ‘Pollutant Ranking’ displays a pollutant ranking table based on concentration and toxicity.

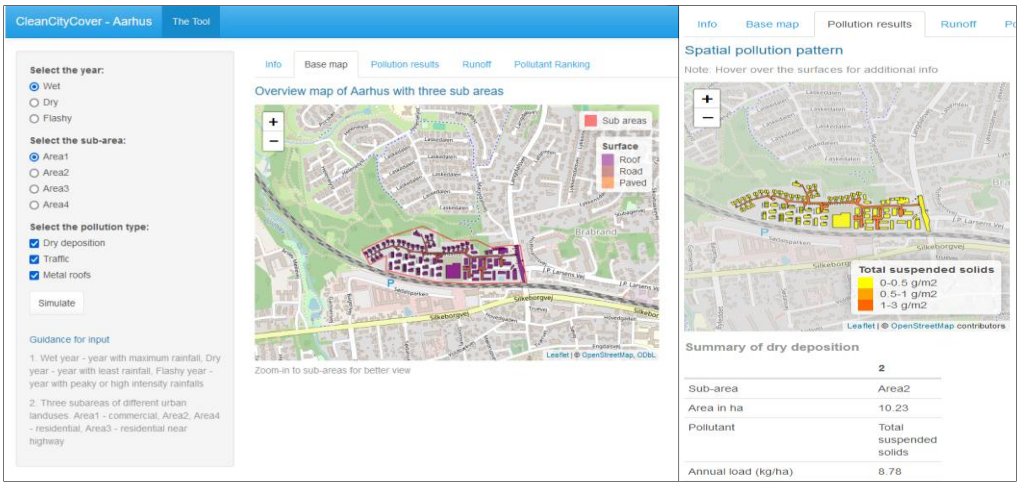

Figure **2.** CleanCityCover interface upon launch (left), featuring the default tab ‘Base map’ zoomed to one of the sub-areas. The Input panel is seen on the left with the three fields to be selected by the user. The Pollution results tab (right) includes an interactive map with spatial pollution pattern and a summary of pollutant load from the area.

Validation of CleanCityCover

The tool CleanCityCover was validated at two study areas detailed in Table 1 for runoff concentration of heavy metals copper, zinc and total nitrogen. A reasonable validation was achieved (NSE from 0.52 to 0.87) at two study areas for three water quality parameters (Figure 3).

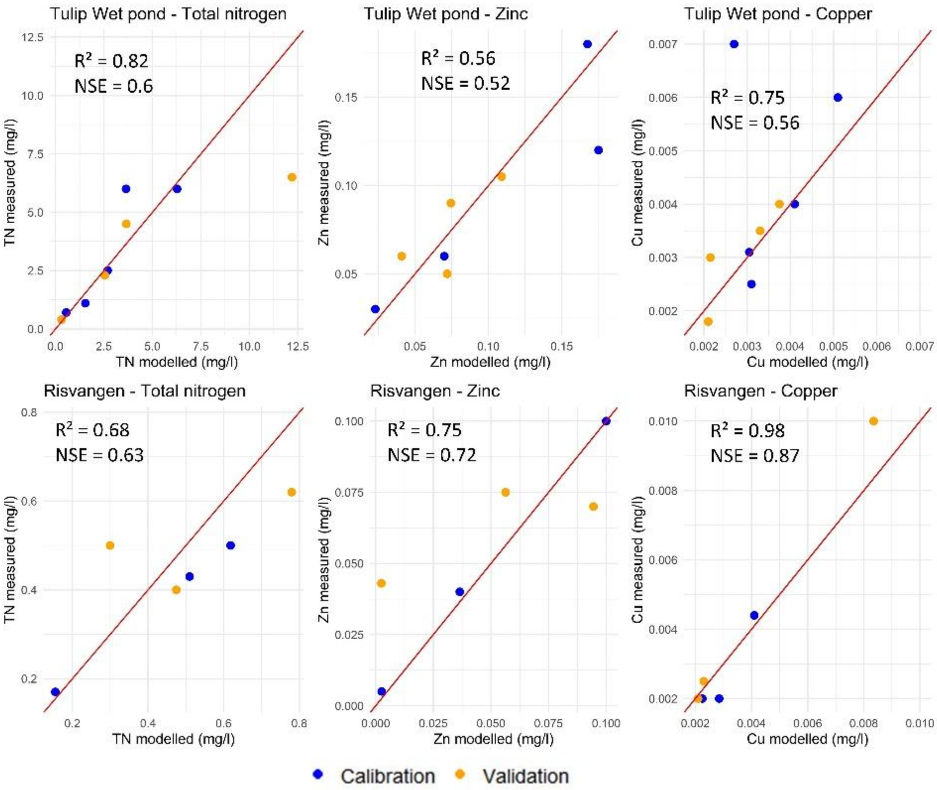

Figure **3.** Measured versus modelled runoff concentrations (zinc, copper and total nitrogen) at two study areas – Tulip Wet pond and Risvangen. The coefficient of determination (R^2) and Nash–Sutcliffe Efficiency (NSE) achieved for validation are shown in each scatterplot. The red line is a 45-degree (1:1) line.

Conclusions and future work

CleanCityCover is a user-friendly interactive tool that can support decision-makers such as from water board managers or urban drainage engineers in planning decentralised methods (e.g.: nature-based solutions) for diffuse pollution control within a city. The tool was successfully validated at three study areas in the city of Aarhus, Denmark for different heavy metal concentrations in runoff. Further validation of the tool is in the way to include other pollution types besides heavy metal, such as microplastic and oil spills. The tool comes with a comprehensive user manual that provides detailed guidance on its use. Furthermore, the development methodology behind the tool is designed to be transferable, making it applicable for adaptation and implementation in other cities.

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