Quality-based drainage of urban rainwater: Potential analysis for the catchment of Hildesheim, Germany

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Highlights

- Quality-based drainage increases water availability in urban neighborhoods by 46 – 72 %
- Polluted rainwater can be treated by existing WWTP without increasing the hydraulic load
- To achieve a low-emission urban drainage, smart use of existing infrastructure is mandatory

Introduction

Urban runoff is often significantly contaminated. In addition to conventional pollutants such as total suspended solids (TSS), chemical or biochemical oxygen demand (COD/BOD), trace metals and nutrients, emerging polltants such as microplastics, micropollutants and pesticides are becoming increasingly important. The amount and type of pollution is mainly dependent on anthropogenic activities, atmospheric deposition and drainage surfaces. For example, runoff from traffic or industrial areas can be heavily polluted with solids, heavy metals, microplastics and micropollutants. (Müller et al. 2020) The increasing pollution of rainwater in terms of quantity and number of pollutants, requires a transformation of the drainage systems to minimise the negative environmental impacts caused by urban drainage. When planning new catchment areas, these new framework conditions can be taken into account. However, the already existing drainage systems consist of a large number of inflexible structures that are mainly built underground and are therefore difficult to access. Thus, a constructive transformation of these drainage systems is only possible in the long term and with a disproportionately high input of resources.

This study presents an innovative and resource-efficient urban drainage concept that enables quality-based drainage and treatment of urban rainwater through smart use of existing infrastructure. The transformation takes place at the operational level through the increased integration of measurement technology, optimised operational concepts and forecasting models. Constructive measures are only considered if they are necessarily required. Additionally, a potential analysis for the catchment of Hildesheim, Germany was carried out to illustrate the potential of the urban drainage concept.

Methodology

The concept of quality-based drainage of urban rainwater

The proposed concept aims to utilise the existing infrastructure in the best possible way for the drainage and treatment of polluted rainwater in order to reduce the need for new infrastructure or constructive transformation of existing infrastructure. Consequently, the existing combined and separate sewer systems are used for the discharge and the municipal wastewater treatment plant (WWTP) is used for treatment of polluted rainwater. WWTPs offer a very good cleaning performance not only with regard to conventional pollutants such as BOD, COD, nutrients and heavy metals but also with regard to microplastics (Sun et al. 2019). Additionally, the treatment performance of the WWTP can be easily expanded through additional process stages, allowing a flexible response to new pollutants.

The polluted rainwater is directed to the WWTP together with the municipal and industrial wastewater. In sub-catchments with a separate sewer system the sanitary pipes are used for this purpose, as long as the hydraulic capacity is sufficient. In sub-catchments with a combined sewer system the combined sewer is used for the discharge of the polluted rainwater. However, combined sewer overflows (CSO) are strictly avoided by limiting the discharge to the sewer system and the WWTP to their maximum capacity.

Therefore, all non-polluted rainwater is decoupled from the sewer system and surplus polluted rainwater, that would cause an overload of the discharge and treatment capacities is decoupled and treated decentrally. The decoupling of unpolluted rainwater refers not only to the spatial decoupling of unpolluted surfaces, but also to the temporal decoupling of rainwater. Through smart control concepts and closing devices, the peak load (first flush) from polluted surfaces could be discharged via the sewer system before closing the sewer system and discharge, infiltrate and use the unpolluted rainwater on the surface and in in urban neighborhoods. Furthermore, the discharge and treatment capacity of the existing infrastructure should be maximized to the best possible extend, e.g. by runoff control strategies and adapted operational strategies on the WWTP, to treat as much polluted rainwater as possible centrally and to avoid CSO.

Quality-based rainwater balance for Hildesheim, Germany

To investigate the potential of the presented concept, a quality-based rainwater balance was carried out for the city of Hildesheim, Germany. Based on the administrative land-use plan the surfaces of the city were classified into “Industry/Commercial”, “Streets”, “Mixed” (mixed areas with commercial and residential areas) and “Residential” (see Figure 1). Industry/Commercial areas and streets were assigned the pollution class III (high pollution). Mixed areas were assigned the pollution class II (moderate pollution) and residential areas were assigned the pollution class I (low pollution).

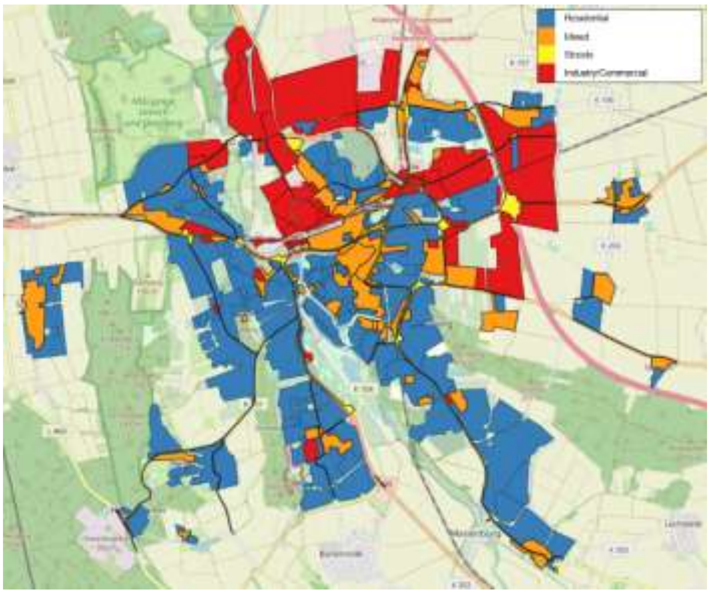

Figure 1. Quality-based surface characterization for the city of Hildesheim, Germany (database: administrative land-use plan)

To convert the total areas into sealed areas, common sealing degrees (80 % for industry/commercial areas, 63 % for streets, 62 % for mixed areas and 35 % for residential areas) were applied. A ten-year rainfall series from Alfeld, Germany was used to calculate the annual rainwater volumes. The average annual precipitation amount within the observation period accounts for 660.5 mm/a. The conversion of the total rainfall to a runoff-effective rainfall was conducted with an average runoff coefficient of 0.7. The scenarios considered in the potential analysis are shown and described in Table 1.

Table 1. Three scenarios for the potential analysis

Scenario	Industry/Commercial	Streets	Mixed	Living
S0	current state (sub-catchments with combined sewer systems are connected to WWTP)			
S1	connected to WWTP	connected to WWTP	decoupled from WWTP	decoupled from WWTP
S2	connected to WWTP	connected to WWTP	temporarily (first 30 min.) connected to WWTP	decoupled from WWTP

To model temporary decoupling in Scenario 2, the 10-year rainfall series was manually modified. The runoff-effective precipitation with temporary decoupling after 30 minutes of each rain event is 417 mm/a.

Results and discussion

Figure 2 shows the results of the rainwater balance as well as the assignment of the partial flows to the three defined usage/treatment paths. The current distribution (S0) of the rainwater does not achieve an optimal utilization of the existing treatment capacities. 25% of the WWTP's inflow does not require any treatment and occupies valuable drainage and treatment capacities. Furthermore, about 1,120,000 m³/a of rainwater requiring treatment (pollution class II and III) are not discharged to the WWTP. Additional rainwater treatment facilities must be constructed and operated in the catchment area for this rainwater, which requires a high expenditure of resources.

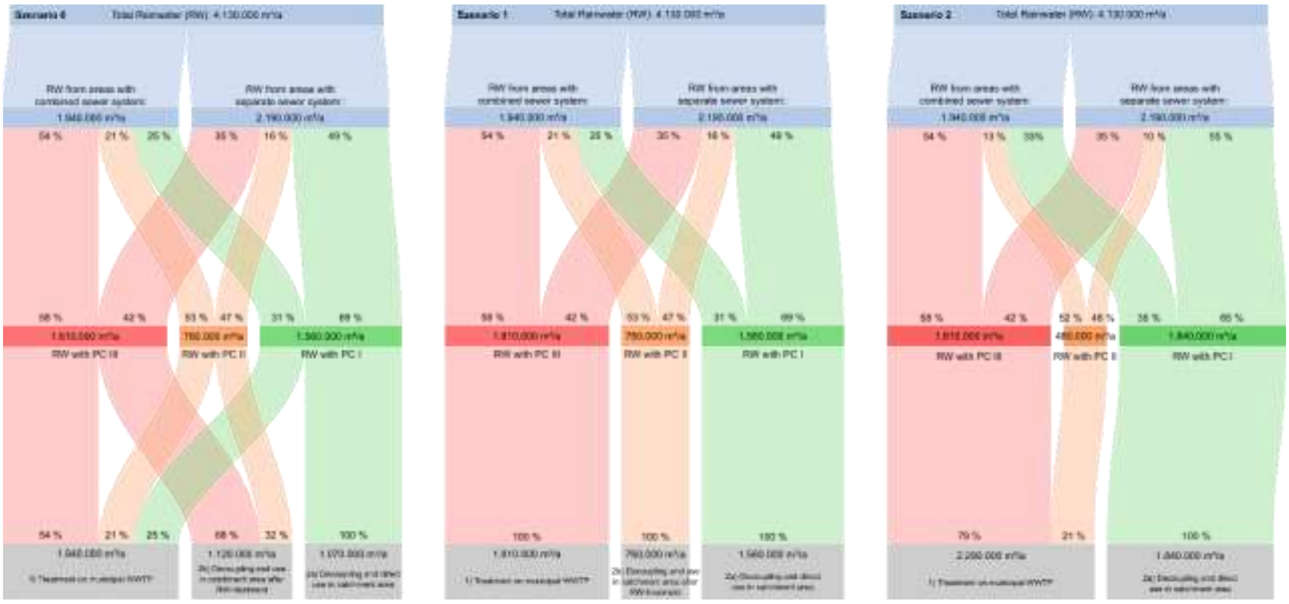

Figure 2. Resulting rainwater quantitites of scenario 0 to 2; differentiated by pollution class (PC) and use/treatment paths

By implementing a quality-based drainage and a smart distribution of rainwater flows to existing discharge and treatment pathways, a target-oriented use of existing infrastructure can be achieved. In Scenario 1, all rainwater with pollution class III can be treated on the WWTP without increasing the total annual flow to the WWTP. At the same time, by decoupling the unpolluted rainwater from the sewer system, additional 46 % of rainwater of pollution class I is available in the catchment area as a valueable water resource. In scenario 2, the available rainwater in the catchment can be increased by 72 % compared to scenario 0 and potentially no additional rainwater treatment in the catchment area is necessary. However, the WWTP's inflow is also increased by 18 % which potentially results in more frequent CSOs and therefore requires an increase of the discharge and treatment capacities by operational optimization.

Conclusions and future work

The results show that the concept of quality-based drainage offers a promising opportunity to achieve a low-emission urban drainage resource-efficiently. The available unpolluted rainwater in the catchment areas could be increased by 46 – 72 %. At the same time, the major part of the polluted rainwater could be treated by the already existing municipal WWTP. This study provides a good starting point for more detailed steady-state and dynamic model calculations, which can be used to improve the data basis and the methodology introduced here. These further investigations will also make it possible to identify transformation opportunities for each individual sub-catchment and also to examine the technical, economic and ecological feasibility.

References

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