Monitoring of a Decentralised Stormwater Treatment System with Rain and Water Level Measurement Technology

Surveillance d'un système décentralisé de traitement des eaux pluviales à l'aide d'une technologie de mesure des précipitations et du niveau d'eau

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RÉSUMÉ

Les systèmes décentralisés de traitement et de rétention des eaux pluviales deviennent de plus en plus importants pour la gestion des eaux pluviales urbaines. L'augmentation des exigences d'efficacité et le nombre croissant de sites opérationnels accroissent les besoins de maintenance, en particulier pour les filtres décentralisés nécessitant une surveillance régulière. Au fil du temps, les charges polluantes peuvent réduire la perméabilité des filtres, entraînant leur colmatage, augmentant ainsi le risque d'inondations et l'entrée d'eaux pluviales non traitées dans les milieux aquatiques. Une surveillance continue permet de minimiser ces risques et garantit un fonctionnement fiable et la protection de l'eau. Cette recherche démontre comment la numérisation et la surveillance basée sur des capteurs peuvent améliorer la résilience, réduire les coûts opérationnels et soutenir la gestion durable des infrastructures hydrauliques urbaines. Une surveillance continue sur sept mois a révélé une diminution progressive de la perméabilité du filtre, nécessitant le remplacement du filtre et validant ainsi l'approche de surveillance.

ABSTRACT

Decentralised stormwater treatment and retention systems are becoming increasingly important for urban stormwater management. Rising efficiency demands and growing numbers of operational sites heighten maintenance needs, especially for decentralised filters requiring regular monitoring. Over time, pollutant loads can reduce filter permeability, leading to clogging of the filter, thus increasing the risk of flooding events and the entry of untreated stormwater into aquatic environments. Continuous monitoring helps to minimise such risks and ensures reliable operation and water protection. This research demonstrates how digitalisation and sensor-based monitoring can enhance resilience, reduce operational costs, and support the sustainable management of urban water infrastructure. Continuous monitoring over seven months revealed a progressive decline in filter permeability, necessitating filter replacement and thereby validating the monitoring approach.

KEYWORDS

Decentralised Stormwater treatment, Monitoring, Sedimentations, Sensor technology, Water filter

1 INTRODUCTION

In the face of climate change, which has resulted in more frequent extreme weather events with intense rainfall alternating with prolonged dry periods, urban infrastructures have been stressed without sufficient adaptation. The lack of climate awareness and adaptation poses significant challenges for stormwater management systems. At the same time, the increasing digitalisation of the water sector, combined with rising demands for pollutant reduction performance, is fundamentally transforming the management of urban water systems (Expósito & Cebollero, 2025). In particular, the field of stormwater and surface-runoff management is experiencing a growing shift towards decentralised treatment and retention solutions. Decentralised systems, such as technical stormwater filters, can meet pollutant reduction demands (Gruening & Schmitz, 2018). Across Europe, there is a growing shift toward such systems to address both expanding impervious areas and stricter water quality standards. However, decentralised systems also increase the number of operational sites, placing additional demands on operators who must ensure reliable operation, maintenance, and performance verification.

Isolated rainfall events, which are often missed by weather radar, require local precipitation measurement (Seltmann, 2021). This helps to gain a realistic assessment of what is occurring at the site. Furthermore, special conditions such as construction, dislodging of dirt and mud from vehicles moving from agricultural areas and many other such cases can significantly impact the permeability and efficiency of filter systems in a short time. For central treatment facilities such as retention soil filters, methods to assess decreasing permeability are equally essential to plan targeted maintenance (Chabert et al., 2025). Even a single heavy rainfall event transporting heavy pollutant loads can clog filter media. With this taken into consideration, continuous metrological monitoring and systematic condition assessment would prove to be crucial to minimise maintenance needs while ensuring effective operation and water protection.

To address this challenge, there has been a growing interest in a sensor-based monitoring approach and digital operational tools. Recent research shows that integrating sensor-based monitoring with data-driven management can enhance the resilience and efficiency of decentralised stormwater systems, making them key components of modern urban water infrastructure (Buddrick et al., 2024). Such continuous monitoring facilitates operators to understand actual system behaviour and detect issues such as filter clogging or reduced permeability before it becomes critical.

2 MATERIAL AND METHODS

The study focuses on pilot installation of decentralised stormwater treatment system in a town located in North Rhine-Westphalia state of Germany.

This SediSubstrator XL is an underground flow-through system to treat polluted urban water in the catchment with sedimentation and adsorption process. It comprises of a distribution pipe for the runoff intake, a 2.4 m long pipe structure with a start and end shaft, and the end shaft containing the SediSorp Plus filter substrate.

The proposed monitoring includes the following sensors and technologies.

- Factory-calibrated Radar water level sensor (NIVUS NivuLink Radar) is installed at the inlet of the system to monitor water level fluctuations every minute.
- An autonomous, low maintenance, calibration-free optical rain sensor (NIVUS RMI Rain Sensor) with a resolution of 0.02 mm is used to record the rainfall every minute.
- The data is logged to the cloud platform NIVUS Web Portal with automatic transfer function. The dataset starting from February 2025 to September 2025 was used for the assessment.
- The permeability of the filter system, as kf -value is calculated using modified Darcy's law, allowing detection of reductions in infiltration capacity and the gradual clogging events. Here, the discharge is derived from the peak 15-minute average rainfall intensity of the event.

$$k_f = \frac{Q*L}{A_{flow}*\Delta h}$$

Where $\mathrm{k_f} = \text{Filter permeability}$, $\mathrm{Q} = \text{Runoff}$, $\mathrm{L} = \text{Flow path length}$, $\mathrm{A_{flow}} = \text{Cross sectional flow area}$, $\Delta\mathrm{h} = \text{Peak water level minus 15 minute water level median before rainfall}$

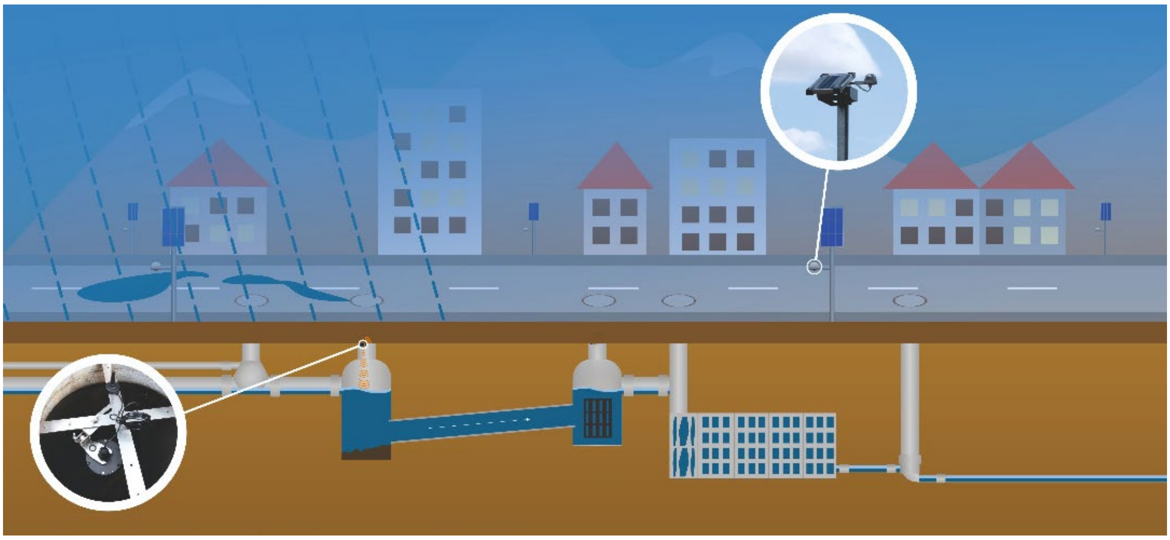

Figure 1. Schematic diagram of the monitoring of decentral stormwater treatment system

The methodology integrates sensor data acquisition, time-series statistical analysis, and performance assessment to evaluate how the stormwater treatment system responds under different rainfall events over time and can be reproduced or scaled-out for other installation sites too. The amount of water that the system can filter out to the water body, and the time it requires to drain out the system helps to identify optimal maintenance intervals accordingly.

3 RESULTS AND DISCUSSION

The high-resolution optical rain sensor captured various rainfall conditions like low-intensity events, long continuous events and intense convective rain events. The 1-minute rain intensity data was particularly helpful to identify the exact time the rain started and when it peaked, providing information on rain pattern and rain quantity very precisely. The water level sensor also provided consistent data, which revealed the distinctive flow pattern, making it directly comparable to the rain data.

Continuous monitoring of the stormwater treatment system showed that filter permeability decreased significantly after multiple rainfall events since the start of the measurement in February 2025. It clearly depicts the exposure of the filter to varied pollutant loads, which gradually clogged it. This detection would not have been possible through conventional inspection schedule.

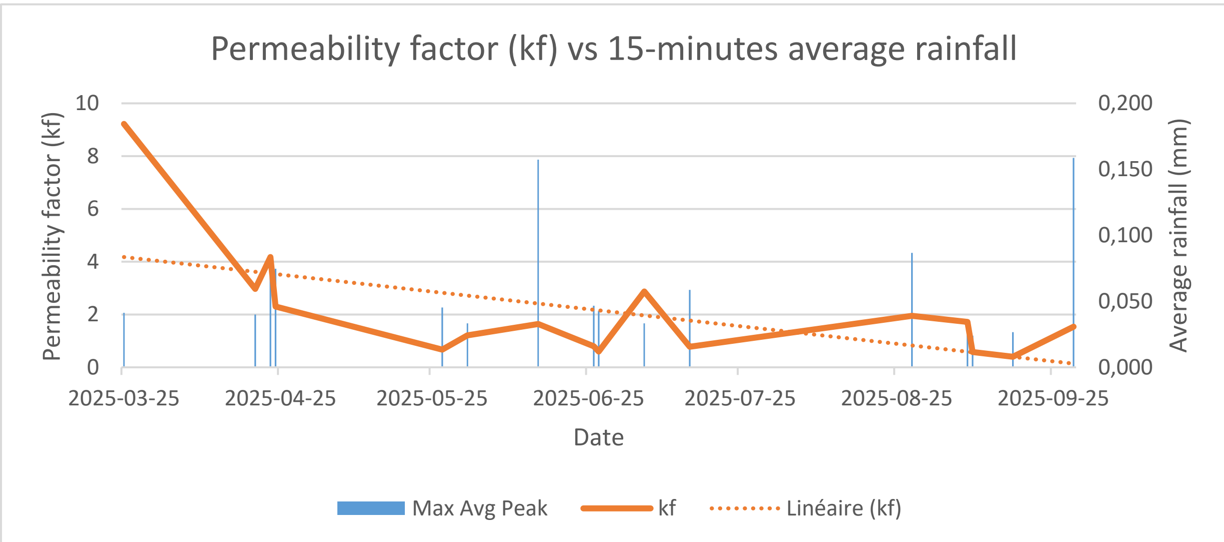

Figure 2. Permeability factors over the period in the pilot location

Towards the end of the monitoring period, the kf values were consistently low, as evident from the monthly average kf-values in Figure 2 and Figure 3. The kf-values in the months of August and September were low and on a downward trend. The overall downward trend from both figures showed cumulated clogging and accumulation of Total Suspended Solids in the filter, which had diminished the treatment capacity of the system. Filter permeability decreased by approximately 79% from initial values in March to the values in September. As a result, the filter was needed to be replaced in late September.

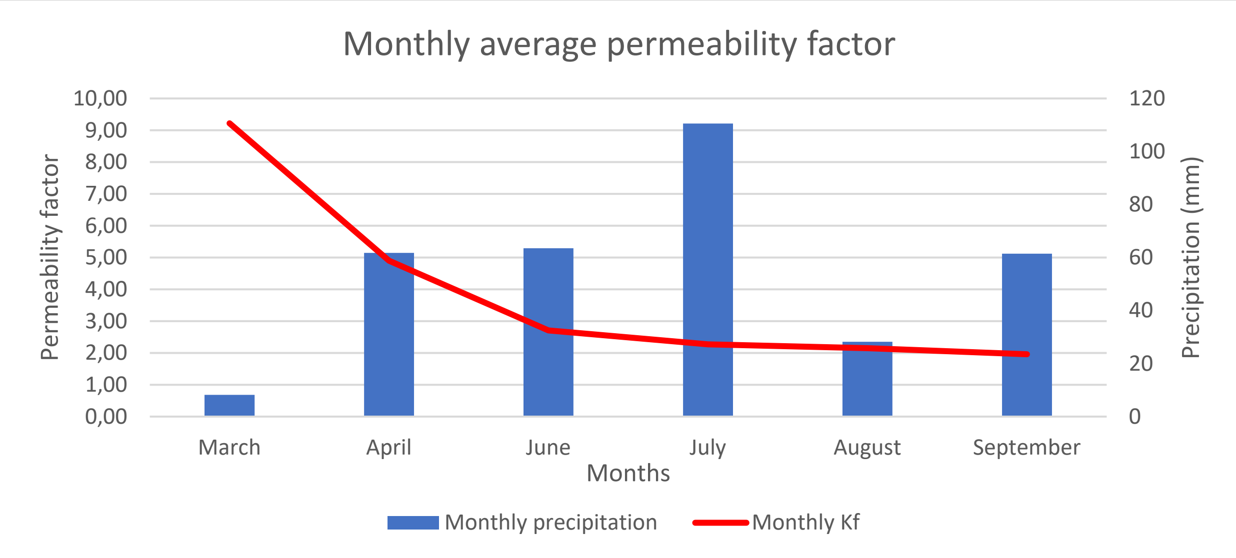

Figure 3. Average monthly filter permeability and monthly precipitation in the pilot location

Ultimately the results show that continuous monitoring facilitates two key benefits for the water sector. Firstly, it enables transparency about the functional condition of decentralised system under real life and daily conditions. Secondly, it allows the operators to stay well-informed and act proactively to improve the resilience and efficiency of the treatment system, reduce environmental impacts, and create a reliable stormwater management plan that could stay strong under increasing climatic stress.

4 CONCLUSIONS

Decentralised stormwater treatment and retention systems, combined with continuous sensor-based monitoring, offer a robust and reliable approach for managing urban runoff under increasingly variable climatic conditions. The findings of this study show that consistent data and the permeability assessment enable early detection of declining filter performance, timely maintenance actions, and minimisation of environmental risk. The observed decrease in permeability, confirmed by the eventual need to replace the technical filter, underscores the value of data-driven monitoring and tracking. Integrating digital monitoring into decentralised systems enhances their resilience, operational efficiency, and long-term sustainability, supporting their effective integration into modern, multifunctional urban water infrastructure.

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