https://doi.org/10.71573/m4jhcv41

Long-term monitoring of sediment accumulation in gully pots using thermal analysis

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Abstract

The sediment accumulation in urban drainage systems can reduce their hydraulic capacity. The installation of sediment monitoring equipment is very limited due to economic and technical factors, such as the high price of existing solutions or the low coverage of these systems for data transfer. This study presents the long-term monitoring of sediment accumulation in six gully pots using temperature-based devices across two urban catchments in Zurich (Switzerland). The monitoring campaign aimed to evaluate the performance of MONTSE devices under real-world conditions, considering seasonal temperature variations. Results showed high accuracy in sediment depth estimations, with mean errors of less than 20 mm compared to in-situ measurements, as well as maximum accumulation rates ranging from 9 to 35 mm/day. Therefore, continuous monitoring combined with prior experiences on sediment accumulation is proposed as an optimal strategy to ensure the optimal operation of urban drainage systems.

Highlights

- Temperature-based devices provide a robust solution for monitoring sediment accumulation.
- Seasonal temperature variations should be considered to analysis heat transfer processes.
- Continuous monitoring of sediment build-up contributes to optimise cleaning tasks.

Introduction

The sediment accumulation in urban drainage systems causes a loss of the hydraulic capacity of these assets. Among other consequences, the loss of efficiency can cause flooding and overflows that compromise urban areas and receiving water bodies. These assets include gully pots, which act as sediment traps, capturing them and preventing them from accumulating in the subsequent pipelines. Monitoring sediment accumulation in these assets is a challenge (Bertrand-Krajewski et al., 2021; Cherqui et al., 2024), as there are plenty of gully pots in an urban network. It is common to carry out periodic cleaning based on previous experiences without knowing the sediment depth at the time of cleaning. Continuous monitoring equipment can be used to optimise cleaning tasks, but those devices with high costs are not a viable solution as their installation would not be scalable. There are low-cost solutions, such as MONTSE, a device that uses temperature measurements and an analysis of heat transfer processes to estimate the depth of accumulated sediment (Regueiro-Picallo et al., 2024b). This device was validated mainly at laboratory scale, reaching accuracies of less than 10 mm (Regueiro-Picallo et al., 2024a), but its performance has not been tested in long-term monitoring campaigns.

This study presents a monitoring campaign in which the sediment accumulation in six gully pots located in the metropolitan area of Zurcih (Switzerland) was estimated using MONTSE devices. The main goal was to evaluate the performance of MONTSE devices in terms of operating conditions (humidity, obstructions, etc.) and temperature analysis, considering seasonal temperature oscillations. For this purpose, annual temperature series were collected, and sediment depth estimations were compared with in situ measurements.

Methodology

MONTSE system

MONTSE is equipped with DS18B20 temperature sensors, which are distributed vertically to measure temperature differences, especially between sensors that are submerged in the standing water and those that are buried in the sediment bed. It can also include an active Dual-Probe Heat-Pulse (DPHP) system to measure the thermal properties of the sediments, which are required to evaluate the thermal transfer processes. Figure 1 summarises the components of the device.

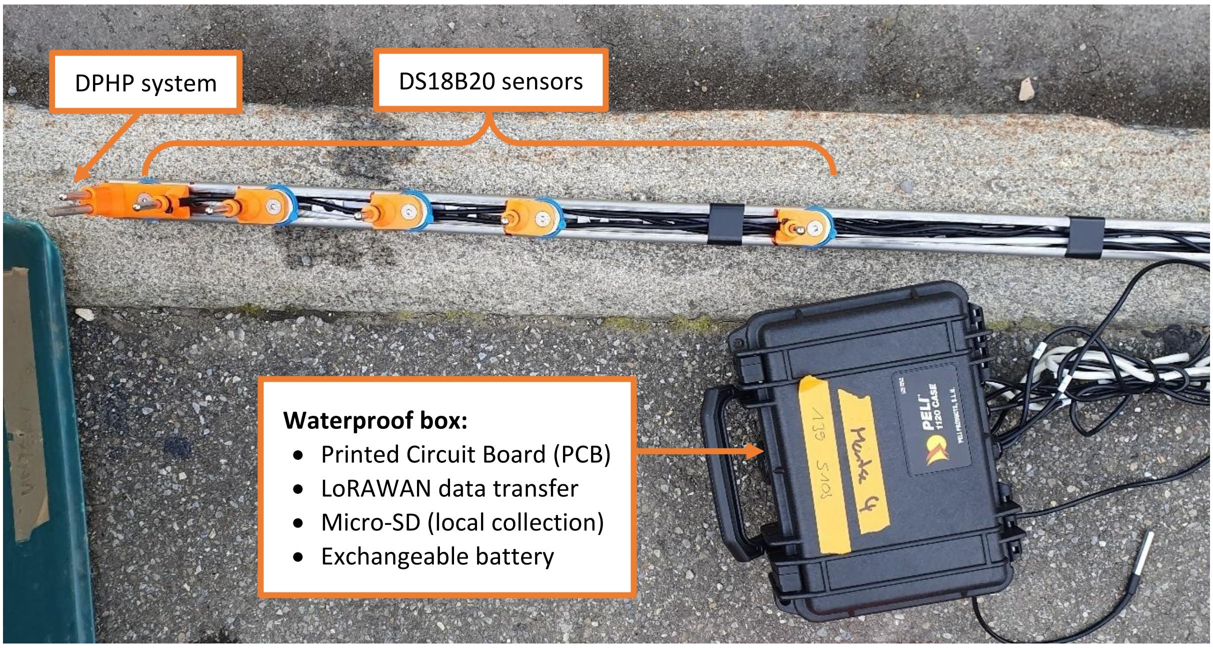

Figure 1. Picture of a MONTSE device before its installation.

Analysis of the heat transfer processes and sediment depth estimation

The sediment depth is estimated by analysing heat transfer processes in gully pots. These processes are enhanced when runoff flows inside the gully pot, causing a temperature gradient in the standing water layer that is transferred slowly to the bottom of the scupper if there is a sediment bed. Thus, the presence of sediment can be simply detected by measuring temperature gradient oscillations in the standing water and in the sediment bed.

The heat transfer process in the sediment bed was simulated using the heat diffusion equation to obtain accurate depth estimations. For this purpose, the temperature of the standing water was defined as the top-boundary condition and the convective heat transfer at the bottom as the low-boundary condition. A 1D model was used as the sensors were installed in the centre of the gully pots, far from the lateral contours (diameters between 700 and 1000 mm). The heat transfer process was simulated by iterating the sediment depth until the best fit was found with respect to the temperature measurements. Sediment depth estimations were compared with in-situ measurements, for which a rod with a measuring tape was inserted into the sediment bed, similar to Rietveld et al (2020).

Case study

The case study is located in the metropolitan area of Zurich (Switzerland). Two urban catchments were selected, Rüschlikon and Wädenswil, in which six MONTSE devices were installed. The MONTSE devices were configured as follows:

- Five devices including six temperature sensors distributed vertically from the bottom of the gully pot and an additional sensor to measure the air temperature. Four of these devices included the DPHP active heating system to measure the thermal properties of the sediments. The objective of the device without an active heating system was to evaluate the estimation of sediment depth using reference values of the thermal properties.
- One device with three spatially distributed sensors and an additional sensor to measure the air temperature. The aim of this device was to find out when a certain threshold of sediment accumulation in the gully pot was exceeded.

Temperature measurements were transmitted using LoRAWAN network at a frequency of 10 min and were also stored locally in each of the systems at a frequency of 1 min. However, the temperature measurements related to the DPHP system were only stored locally due to the high temporal resolution required (1 s). In addition, monthly field trips were carried out to check the devices and download local data, and to perform in-situ measurements of the sediment depth. The data will not be openly available until the end of the project.

Results and discussion

Temperatures were collected in the six gully pots for one year with a data availability rate of 85%. As an example, Figure 2 shows a weekly temperature series in a gully pot. Temperature oscillations were observed during rain episodes of great intensity or duration, especially in those where there was a significant runoff inflow. Local rainfall data from MeteoSwiss was also used to make this comparison.

Using the temperature series and knowing the position of each of the sensors, it was possible to detect the presence of sediments and estimate their depth. As illustrated in Figure 2, the sensors positioned at the bottom of the gully pot and at a distance of 100 mm were buried within the sediment bed on 18th April. This indicates that the depth at that moment ranged between 100 and 200 mm. However, the rain intensity the next day led to the sensor located 100 mm from the bottom being submerged in the standing water layer, as the temperature oscillation matched with the rest of the upper sensors.

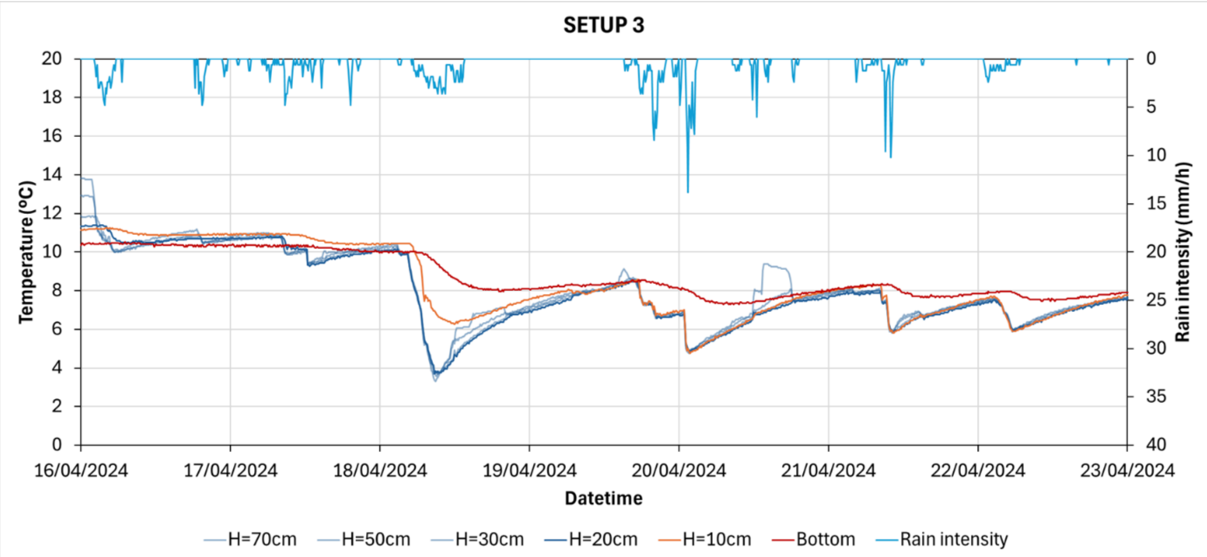

Figure 2. Temperature oscillations in the standing water layer (light- and dark-blue lines) and sediment bed (orange and red lines) of a gully pot collected with a MONTSE device, combined with rain intensity data collected from MeteoSwiss Agency.

A temperature gradient in the standing water layer higher than 1ºC was selected to determine the rainfall-runoff events and subsequently perform accurate sediment depth estimations. Poor accuracy of the estimations was found when the temperature oscillations within the sediment layer were lower than this threshold. In addition, the sign of the temperature gradients depended on the season; there was a tendency to observe positive gradients during the summer months (June, July and August) when the air temperature was much higher than inside the gully pots, while negative gradients were the common trend during the rest of the year (e.g., Figure 2). Furthermore, during periods of low external temperatures in winter, the measurement of temperature oscillations was restricted.

Sediment depth was estimated by iteratively simulating the heat transfer processes. For this purpose, we analysed 18 hours of temperature data from the start of the temperature oscillations in each event. The selection of the simulation period was based on the analysis of the relative distance between the water-sediment interface and the position of the temperature sensors buried in the sediment layer. Under these conditions of temperature series analysis, absolute mean errors in the sediment depth estimations were less than 20 mm with respect to in-situ values, similar to what was observed at a laboratory scale (Regueiro-Picallo et al., 2024b). It should be noted that the in-situ measurements were subject to some uncertainty, due to the compaction of the sediment when the rod was positioned on the sediment surface. Considering the long-term sediment accumulation in the gully pots, total sediment build-up values of between 50 and 160 mm were obtained for the period of study, with maximum accumulation rates of between 9 and 35 mm/day.

Conclusions and future work

The use of MONTSE in gully pots was proved to be an effective approach for long-term monitoring of sediment accumulation. The devices showed a high accuracy in estimating sediment depth, with mean errors of less than 22 mm compared to in-situ measurements. This accuracy was maintained even under varying seasonal conditions, highlighting the robustness of the device. Therefore, the ideal option to optimize cleaning and maintenance processes is to combine the monitoring of sediment accumulation and the knowledge of previous local experiences. Future work will focus on further refining the heat transfer analysis methods and expanding the application of MONTSE devices to other urban drainage systems.

Acknowledgement

The monitoring campaign was funded by the project "Messungen der Sedimentdicke (MESSD)" as part of the contract "2023-090/Projektvertrag MESSD/Eawag – Tiefbauamt Kanton". The authors acknowledge the professional support of the Applied Chemistry Group members of the OST – University of Applied Sciences of Eastern Switzerland during the monitoring campaign, as well as Noemi Buri (Eawag) for her assistance with the installation of MONTSE devices. The work developed by M. R.-P. was funded within the postdoctoral fellowship programme from the Xunta de Galicia (Consellería de Cultura, Educación e Universidade, ED481D-2024-023).

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