Effects of Environmental Factors on Sediments in the Urban Sewer Systems of Kyoto

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Introduction

Sediment accumulation can reduce the drainage capacity of sewer systems, and thus increase the risk of urban flooding and jeopardize the safety of urban environments. The interaction between multiple environmental factors drives sedimentation in sewer systems, but this interaction is poorly understood. To fill this gap, this study examined the interaction between five categories of environmental factors (population, traffic, climate, air quality, and wastewater quality: 25 factors overall) and the effects of these factors on sediment accumulation in different sewer system structures (open channels (OCs), circular channels (CCs), junctions) in Kyoto, Japan, from 2014 to 2023.

Hypothesizes and aims

Based on the monthly variations of each EF and sediment data at the urban scale, this study hypothesizes that the interactions of the above five EF categories will lead to changes in the sediment content of the sewer system and that the influence of the different EFs is not consistent, and that some of the EFs should not be ignored in predicting the sediment content. The study aims to develop a conceptual framework for understanding the role of EFs in sediment content in the sewer system. Specifically, the objectives were, 1) to characterize the direct and indirect contribution and interactions of each EF category to sewer sediment accumulation, 2) to assess the significance of each EF as a sewer sedimentation driver, and, 3) to identify those EFs whose input should be invariably included in sewer system sedimentation models. An overall understanding of the role of these factors and their impact on sediment enhances understanding of sedimentation in urban sewer systems and informs sewer system design and maintenance, especially about sedimentation control, and will be beneficial to the decision-makers concerned in taking timely and effective measures to control the more important factors affecting sediments.

Methodology

Fig. 1 summarizes the progression of this study. In the first stage, EFs (population, traffic, climate, air quality, and water quality) and sewer sediment data were collected and brought together into a database. The monthly sediment content in different branches of the sewer system was set as a response factor.

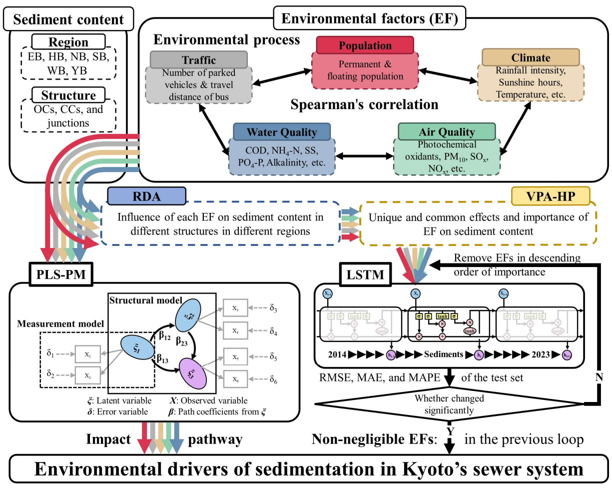

Fig. 1. Study flowchart.

In the second stage, Spearman's correlation was used to analyze the temporal correlation of the various EFs, and redundancy analysis (RDA) was employed to explore the influence of each EF on sediment accumulation in different sewer structures across the sewer system of Kyoto. The variation partitioning analysis with hierarchical partitioning (VPA-HP) was applied to analyze the unique and common effects of the five EF categories on sewer sedimentation. VPA-HP quantifies the importance of each EF as the ratio of the individual influence of this EF to the total influence of all EFs on sediment accumulation. Spearman's correlation was also used to determine the positive or correlation impact of each EF. In addition, partial least squares path modeling (PLS-PM) was applied to construct the impact pathways (including direct and indirect effects) of each EF category on sediment accumulation based on determination coefficients, path significance, and goodness of fitting.

In the third stage, a Long Short-Term Memory network (LSTM) model was employed to simulate temporal changes in sewer sedimentation. To identify the non-negligible EF drivers of sedimentation in the sewer system, a censoring cycle was performed based on the importance weights of the EFs (from VPA-HP results) input into the LSTM model and some evaluation criteria were used to judge the model prediction effectiveness.

Results and conclusion

The interactions between population, traffic, climate, air quality, wastewater quality, and their influence on sediment accumulation in the sewer system of Kyoto were examined, and the following contributions are noted:

(1) Population growth leads to increased traffic flow, which promotes the combustion of fossil fuels and stimulates the resuspension of road dust with the help of high vapor pressures, leading to air pollution. Resuspended PM and some pollutants accumulate at the surface through dry deposition captured by water vapor (high humidity) and are washed into the sewer system by rainfall (i.e., wet deposition), which leads to the accumulation of sediment in the sewer system.

(2) Sunshine enhances the production of secondary pollutants (e.g., photochemical oxidants), thereby limiting sedimentation to the sewer system during dry and wet deposition.

(3) Sediment accumulation in circular channels was mainly influenced by a combination of climate change and air and wastewater quality. The NH_4-N, PO_4-P, and alkaline substances in the wastewater enhanced sedimentation in circular channels via coprecipitation or adsorption.

(4) LSTM can predict the sediments in junctions and the whole system better in the early stage using the above environmental factors, but the prediction for sediments in circular channels is poor due to the weak explanation of the environmental factors mentioned above.

Notably, model construction in other regions can refer to the methods and theories of this study and analyze them specifically with local conditions.

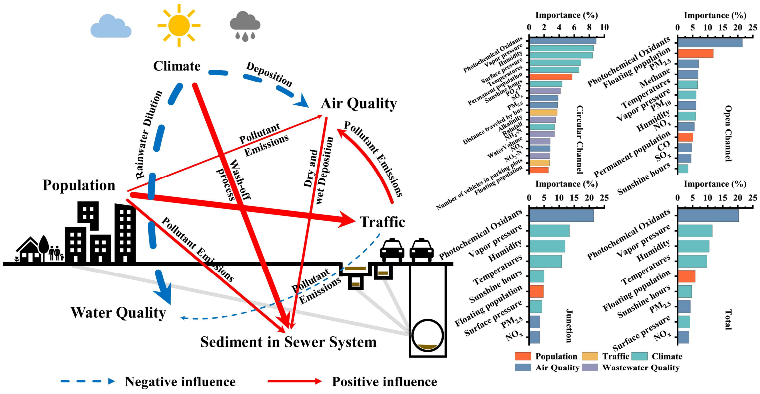

Fig. 2. Graphical abstracts.