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# An Integrated Assessment of Urban Drainage System Performance and Risk in Built-Up Areas

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## Abstract

Since the 1980s, alongside China's large-scale urban construction, urban stormwater and sewage drainage systems have also undergone rapid development. By the end of 2023, the total length of urban drainage pipelines in China reached 952,500 km, with over 5,000 urban sewage treatment plants in operation, and a total treatment capacity of 227 million cubic meters per day (Hongchen, 2025). However, the rapid development of urban drainage systems has gradually exposed serious issues, primarily in the following three areas: (1) The lack of proper planning and design for stormwater major drainage systems in urban development has led to an increasing risk of urban flooding; (2) illegal connection of stormwater and sewage pipes, the abnormal "combined sewer" system, and a lack of effective operation and maintenance management, leading to severe issues such as sedimentation and overflow risks; (3) low pollutant treatment efficiency in sewage systems. This paper uses the TK River Basin, China, as a case study, employing a comprehensive approach that combines continuous monitoring, a physics-based model, and a data-driven model to conduct an integrated assessment of performance and risk in the existing urban stormwater and sewage drainage systems, providing support for the renovation, upgrading, and operation and maintenance management of urban drainage system.

## Highlights

- Assessment of urban flood risk based on a 1D/2D hydraulic coupling model.
- Assessment of pipeline network performance and risks based on monitoring and modelling.
- Prediction of influent volume and water quality at treatment plants using a data-driven model.

## Introduction

This study uses the TK River Basin, China, as a case study. The basin is still in a rapid urban development phase, with the expanding urban areas and population growth further increasing the pressure on the existing drainage system, thereby raising the risk of urban flooding under extreme rainfall conditions. At the same time, serious issues such as illegal connection and mixing of stormwater and sewage pipelines have emerged during the rapid urban construction process. These issues, combined with groundwater infiltration and river backflow into the sewage system, have led to the influx of multiple water sources—wastewater, stormwater, groundwater, and river water—into the sewage system, diluting the pollutant concentration in the sewage network and causing the influent pollutant concentration at sewage treatment plant to be too low. To address these issues, this study uses a 1D/2D coupled stormwater system model (Salvan, 2016) and, based on the simulation results, assesses the flood risk for each building in key areas (Schmitt, 2020). An early warning system is then developed based on different flood risk levels. Additionally, by combining the sewage system hydraulic model, data-driven model, and continuous pipe water level monitoring, this study evaluates high-risk sections

of the sewage network where external water inflow and pollutant sedimentation are prevalent, and, based on rainfall forecasts, predicts the influent volume and pollutant concentration at sewage treatment plants under different rainfall conditions.

## Methodology

### Physics-based Model

A coupled model of 1D river channels, 1D stormwater networks, and 2D surface ground is built using Info Works ICM to simulate and assess the drainage capacity of urban stormwater systems, as well as surface runoff and flooding risks when the drainage capacity is exceeded. For key areas and different building units, based on the simulation results of flood depth and duration under varying rainfall conditions, the potential impacts on human safety and property loss are evaluated, and flood risk levels for different buildings are classified and field-validated.

### Data-driven model

Based on the statistical analysis of long-term continuous operation data from the LT Sewage Treatment Plant at the end of the basin, and taking into account the domestic sewage discharge characteristics in the region (COD concentrations ranging from 284 to 366 mg/L) as well as stormwater runoff pollution levels (COD concentrations ranging from 64 to 115 mg/L), a data-driven model is developed to predict the daily influent volume and pollutant concentration under different rainfall scenarios.

### Analysis of Continuous Sewage Pipeline Water Level Monitoring Data

Based on continuous level monitoring of different sewage pipeline sections, an evaluation and analysis are conducted to identify sections with severe external water inflow and infiltration.

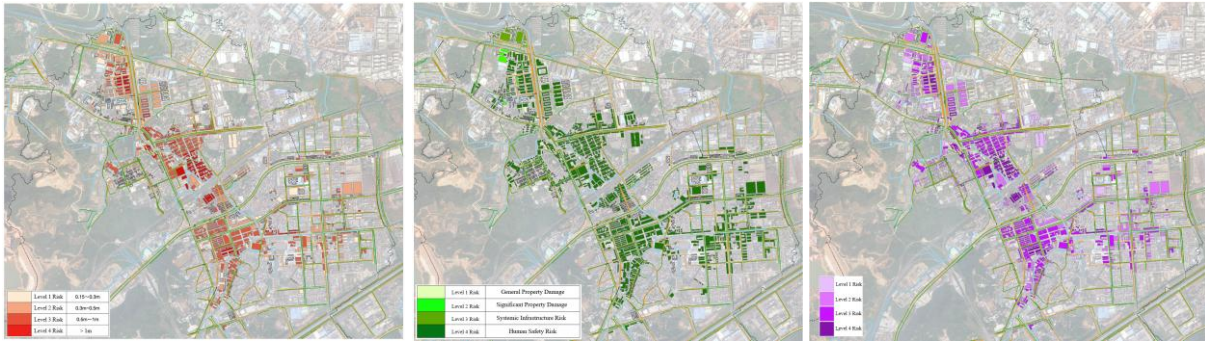
## Case study

Taking the TK River Basin, China, as an example, the total area of the basin is approximately 24.39 square kilometers, with an overall terrain that is high in the southwest and low in the northeast. The central and eastern parts of the region have relatively flat terrain and are concentrated areas for both existing and planned urban development. The TK River Basin contains two reservoirs and three rivers, including SZK Reservoir, LY Mountain Reservoir, and three rivers: TK Stream and its tributary SJL Stream, as well as LY Mountain Stream. The region has a total of 972.5 kilometers of stormwater pipelines, 979.6 kilometers of sewage pipelines, and 23.6 kilometers of combined sewers.

## Results and discussion

### 1) Flood Risk Assessment

The assessment first determines the flood risk level of different buildings based on the surrounding water ponding depth. The risk levels are as follows: Level 1 risk corresponds to a water depth of 0.15–0.3m, Level 2 risk corresponds to a water depth of 0.3–0.5m, Level 3 risk corresponds to a water depth of 0.5–1m, and Level 4 risk corresponds to a water depth greater than 1m. Next, considering different types of disaster losses, such as personal injury, unquantifiable property damage, and quantifiable property damage, different risk levels are determined. The levels are as follows: Level 1 risk corresponds to general property damage, Level 2 risk corresponds to significant property damage, Level 3 risk corresponds to systemic infrastructure risk, and Level 4 risk corresponds to human safety risk. Finally, through a comprehensive evaluation, the individual building risk results for the entire area are obtained (Figure 1). There are 281 units with Level 1 risk, accounting for 16.7% of the total; 388 units with Level 2 risk, accounting for 23% of the total; 608 units with Level 3 risk, accounting for 36.1% of the total; and 125 units with Level 4 risk, accounting for 7.4% of the total.



**Figure 1.** The results of urban building flood risk assessment (including inundation risk, damage risk, and integrated risk)

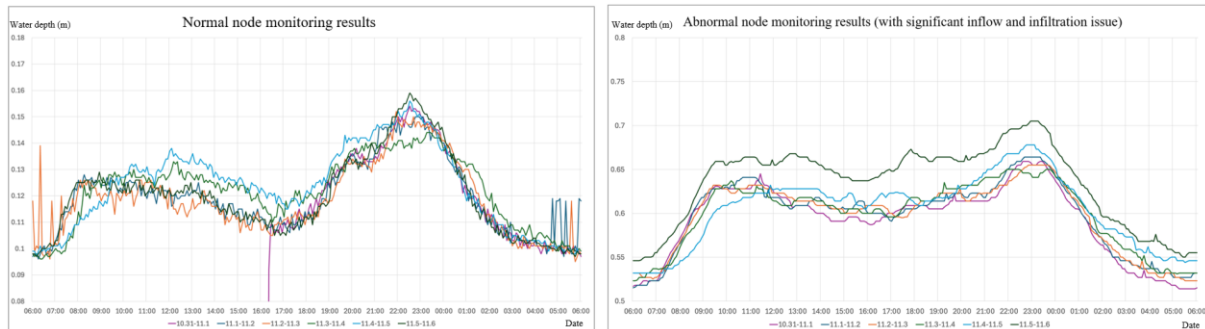
Upon acquiring the simulation results, perform elevation-based inspections for high-risk buildings. Field assessments compared occupiable floor elevations against modelled flood levels to refine risk evaluations (Figure 2). Integrating precipitation alerts and forecasts, issue pre-emptive evacuation advisories to vulnerable residents.



**Figure 2.** Field assessment examples for simulation assessment outcomes

## 2) Sewage Network Failure Risk Assessment

Based on the monitoring of the sewage system in the TK River Basin, the peak water level at the source and at the end of the sewage system are determined (Figure 3). The peak water level at the source differs between weekdays and weekends, with the main peak on weekdays occurring between 7:00 and 9:00 AM, and the nighttime peak occurring between 8:00 and 11:00 PM. At the same time, the peak level in the main pipeline at the end of the system occurs between 10:00 AM and 12:00 PM, with the nighttime peak occurring between 10:00 PM and 1:00 AM, which is approximately 2 hours later than the source peak level, and exhibiting typical diurnal variation characteristics of sewage flow. Based on the peak water usage data and combined with the flow characteristics of the drainage system, the basic flow process for each sewage drainage zone is determined. For normal pipeline sections, the position of the daily peak and trough remains relatively consistent. In pipeline sections with significant external water inflow and infiltration, the water level process line of the sewage system gradually rises each day due to the influx of external water.



**Figure 3.** Comparison of normal and abnormal sewage pipeline network water level monitoring results

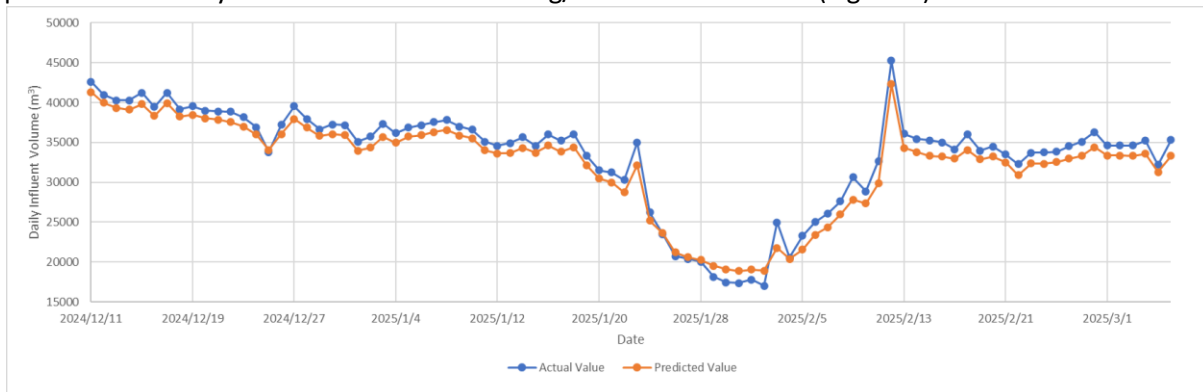
Due to factors such as pipeline slope and diameter connections, in actual operation, many pipeline sections are more prone to issues like sedimentation and corrosion compared to other sections, due to insufficient slope, poor flow, and other reasons. This method is used to determine the sedimentation risk for different pipeline sections of the sewage system in the TK River Basin. According to the model analysis, high-risk sedimentation sections account for 12.05 kilometers, or 11.2% of the total length of the main sewage pipeline network. high-risk sedimentation sections account for 19.46 kilometers, or 18.1% of the total length. Medium-risk sedimentation sections account for 31.62 kilometers, or 29.4% of the total length. Low-risk sedimentation sections account for 44.27 kilometers, or 41.2% of the total length.

### 3) Sewage Treatment Plant Influent Volume and Water Quality Prediction

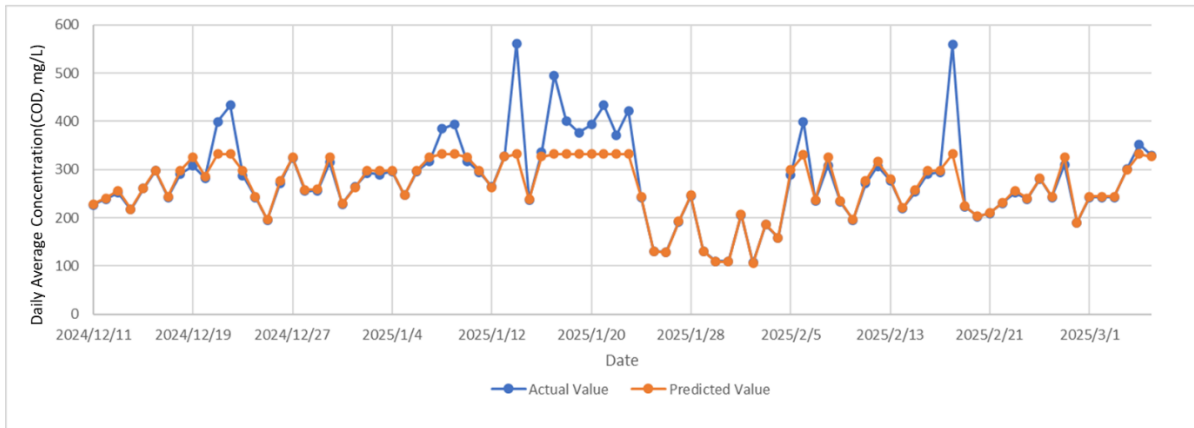
A data-driven machine learning framework was developed to predict both influent volume and influent quality (represented by COD) at a wastewater treatment plant (WWTP) based on historical monitoring data (Piadeh, 2023), with a focus on assessing the impact of rainfall-induced inflow on both the treatment capacity and influent water quality of the WWTP. The method focuses on feature engineering strategies that extract key temporal and cumulative indicators relevant to system behaviour, and leverages ensemble learning to improve prediction performance.

For features construction, we considered the hydraulic and environmental memory effects of the urban sewer system, as well as the correlations among influent volume, water quality, rainfall, and water supply. In the influent volume prediction model, input features include: Previous day's influent volume; Current day rainfall (using forecasted rainfall in practical applications) and Past 3-day cumulative rainfall; Past 3-day average influent volume; Past 3-day average water supply. For COD concentration prediction, we further included: Previous day's average COD concentration; Past 3-day average COD concentration.

The model was built using a stacking ensemble method, combining Random Forest and Multi-Layer Perceptron (MLP) as base learners, with a Linear Regression meta-learner to integrate their outputs. The dataset was split with 80% for training and 20% for testing. The influent volume model achieved a Root Mean Square Error (RMSE) of 1471.12 m<sup>3</sup>/day and a coefficient of determination (R<sup>2</sup>) of 0.947 (Figure 4), indicating excellent agreement between predictions and actual observations. The COD prediction model yielded an RMSE of 47.41 mg/L and an R<sup>2</sup> of 0.708 (Figure 5).

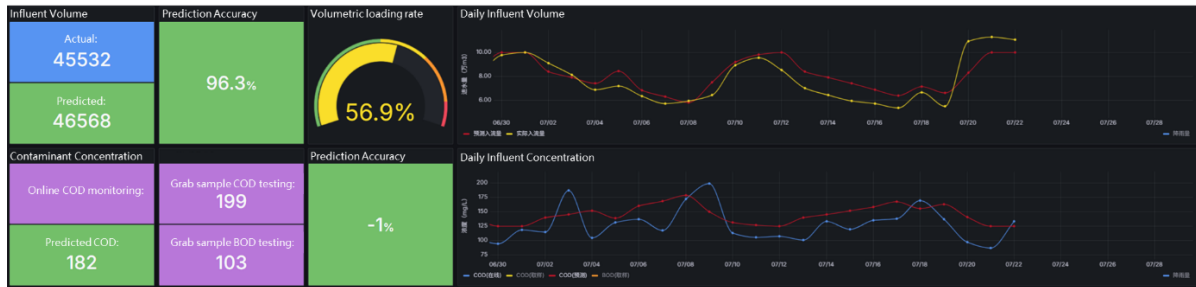


**Figure 4.** Comparison of the predicted and actual daily influent volume at the wastewater treatment plant



**Figure 5.** Comparison of the predicted and actual daily average influent concentration (COD) at the wastewater treatment plant

The integrated data management system was established to assimilate predicted influent parameters (total daily volume and daily average contaminant concentration) at the WWTP (Figure 6). The system visualizes both historical measurements and short-term forecasts, particularly generating rainfall-triggered inflow projections to facilitate anticipatory process control strategies under storm conditions.



**Figure 6.** The integrated data management system dashboard

## Conclusions and future work

Based on the integrated assessment of the stormwater and sewage drainage system using modelling and monitoring, the classification of risk levels based on the evaluation results supports the subsequent operation, maintenance, and improvement plans for the stormwater and sewage pipeline network.

## Acknowledgement

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