Urban flooding risk assessment and sewer rehabilitation evaluation of an old neighborhood in Ningbo, China

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Highlights

- There are a lot of adverse-slope pipes in the sewer network of the old neighborhood.
- The spatial distribution of inundation risk is generally consistent across scenarios.
- Urban flooding can be effectively reduced by source control and sewer rehabilitation measures.

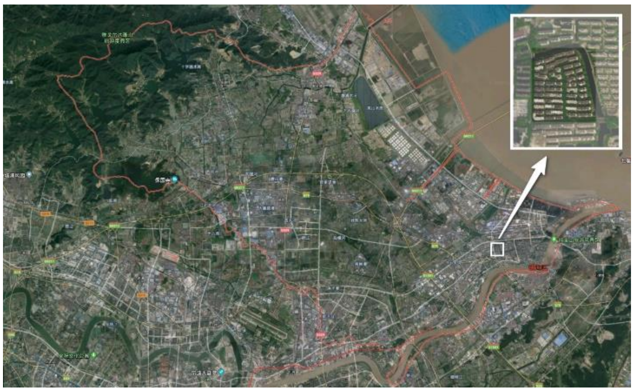
Introduction

Many cities around the world suffer from urban waterlogging due to rapid urbanization and frequent extreme weather caused by climate change. Especially, the old neighborhoods have various drainage issues owing to their aged infrastructure, making it more difficult to cope with rainstorms. Additionally, the renovation of old neighborhoods is also a major national program at present in China. Therefore, it is necessary to assess the urban flooding risk and the efficiency of retrofitting outdated drainage systems. In this study, the sewer network of BL old neighborhood in a coastal city Ningbo, China, was studied by using the InfoWorks Integrated Catchment Modelling (ICM) model. The waterlogging risk in the study area during rainstorms was analyzed. Source control and pipe network rehabilitation measures were also modelled.

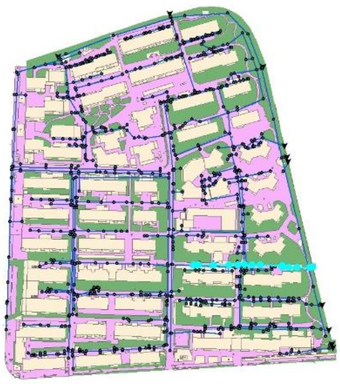
Methodology

Study site

The study site is located in Zhenghai District, Ningbo, China (Figure 1a). The total area is about 7.13 ha with high population density. It is a relatively independent drainage area, surrounded by Zhongda River to the north and east, Daximen Road to the south and Huancheng Road to the west, respectively. The land use types in the study area fall into three categories, that is, roads and squares (7%), green space (25%) and building land (68%), as shown in Figure 1b. The construction standard of the original drainage pipes in the district is low and the rainwater and sewage are mixed, causing poor drainage and waterlogging problems.



(a)



(b)

Figure 1. Study site: (a) location; (b) land use types and sewer pipelines

Hydraulic modeling of the drainage system requires data information on the pipe network, hydrology and hydraulic parameters (Artina, 2007). The data were provided by relevant government departments and Zhenghai Survey and Design Institute. The rainfall data and the flow information were obtained through field monitoring.

Model development and calibration

After some simplification of the sewer network under study, a model with 718 inspection wells, 725 pipelines and 6 discharge points was built up. Based on the land use type, topography and the direction of the combined drainage pipes, the Tyson polygon method was applied to divide the whole catchment area into 337 sub-catchments. The ground TIN model was used for two-dimensional coupling after GIS processing of the ground elevation data. According to the actual land use situation, different catchment areas are assigned with different surface runoff parameter values. Appropriate runoff generation model and confluence model were selected according to Peng (2016).

According to the general calibration rule for hydraulic models used in the urban drainage system, the relative error of the total volume and the deviation of the peak occurrence time in the simulation are acceptable within 20%, and the allowable error of the peak runoff is 25% (Mannina, 2012; Schellartet, 2012). The parameters were calibrated and validated by comparing the measured values with two typical rainfall events, respectively. The comparisons were given in Table 1.

Table 1. Simulated results of calibration and validation

Typical rainfall event	Volume simulation values (m^3)	Volume measured values (m^3)	Volume error (%)	Peak simulation values (L/s)	Peak measured values (L/s)	Peak error (%)
Aug. 27	36.06	32.63	10.2	22.75	24.19	-6.3
Aug. 29	61.29	61.90	-1.0	20.92	18.98	10.2

Urban flooding risk assessment methodology

In this study, the scale of the study area is small, which requires relatively high accuracy modeling and assessment. The scenario simulation assessment method was selected. The main steps of applying the scenario simulation method for urban flooding risk assessment are: (1) determining the type of disaster; (2) determining the impact range of the disaster; (3) determining the data of the disaster body involved; (4) classifying the risk level (Wu, 2017).

Scenarios for modelling

A total number of six simulation scenarios were selected, which corresponds to 2-hour rainfall events with different recurrence periods: 1, 3, 5, 10, 20 and 50 years. The rainfall intensity was obtained by calculating the local rainfall intensity formula, and the design rainfall event was generated by using the Chicago rain pattern.

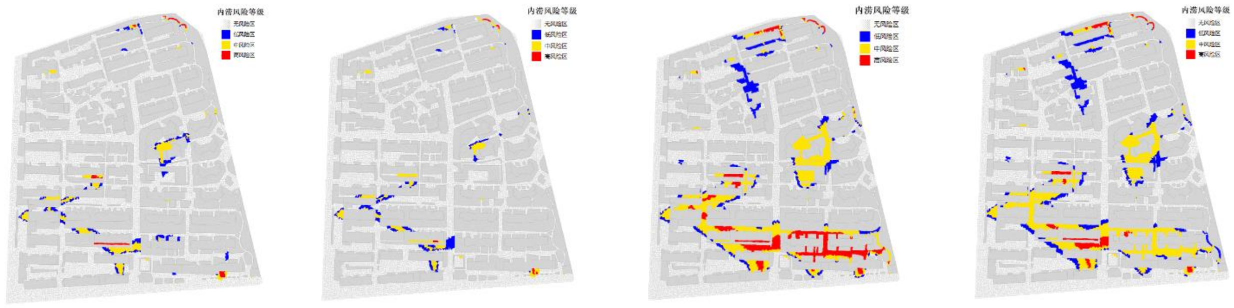
Results and discussion

Analysis of manhole overflow and sewer load

Results indicate that a large number of manhole overflows and sewer pipes run full. The number of overflow manholes increases with larger rainfall recurrence period, and so does the overflow volume. For the 50-year return period rainfall, almost half of the total manholes overflows. The number of overspilled manholes for rainfall recurrence periods less than or equal to 10a increases significantly with the recurrence period. The existing sewer network has pipes with insufficient drainage capacity from the beginning of the 1-year return period. Under rainstorms with greater than 5a recurrence period, more than 95% of the pipes are pressurized. This can be attributed to that there are a large number of adverse-slope pipes in the drainage system. Therefore, it is necessary to develop a pipeline rehabilitation program that meets the desired design criteria.

Urban flooding risk assessment

According to the distribution maps of waterlogging risk under different simulation scenarios, it can be found that waterlogging risk increases with the increase of rainfall return period (Figure 1. a&c). The area of each risk level in the study area increases significantly when the return period is greater than 3-year. The spatial distribution of waterlogging risk is basically the same in different return periods, except that the area of each waterlogging risk area increases with the increase of precipitation intensity. Combined with the elevation information, the medium-high risk of waterlogging is mainly distributed in the roads with low topography in the south-central part of the study area, which needs to be taken with care during the reconstruction.



a. 5a-Current situation b. 5a-Rehabilitated c. 50a-Current situation d. 50a-Rehabilitated

Figure 1. Distribution of flooding risk before and after rehabilitation

Sewer rehabilitation evaluation

The drainage capacity of the current pipe network system is relatively fragile (Figure 1). Therefore, drainage system rehabilitation is needed to reduce the risk of waterlogging. To achieve this goal, the following two measure were tested in this study. First, introducing some sponge (low impact development) measures for source control, including changing roads to permeable pavement and converting greenery in front of homes to low elevation greenbelt. Second, adjusting the pipes with adverse slope to meet their hydraulic slope requirements. A new pipeline is also added on the eastern section to relieve the drainage pressure of the existing pipeline.

The simulated results show the flooding risk area was significantly reduced after the rehabilitation. The overall risk level of the study area shifted to low-risk under different rainfall return periods, and there were no high-risk areas for scenarios below the 3-year return period rainfall. The combined risk area was reduced by 28.5%, 23.7%, 21.1%, 17.0%, 12.7% and 7.6% under six design rainfall scenarios, respectively. The waterlogging risk reduction by sewer rehabilitation and source control gradually falls down with increasing return period.

Conclusions and future work

In this study, a drainage model of an old neighborhood in Ningbo, China was developed. The urban flooding risk under different scenarios were assessed. The results show that source control and pipe network rehabilitation can effectively prevent and control waterlogging, and are particularly effective in low recurrence periods. The related analysis provides technical support for the operational assessment of the current drainage network and the optimization and renovation of the sewer network system in the old neighborhoods of coastal cities. The next step will be to implement the retrofit measures in the field, evaluate their practical effects and conduct a study on the long-duration storm recurrence period.

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