1. Brief introduction of the IFMS/Urban model

（1）Development of IFMS/Urban model

In 2014, taking the opportunity of the National Flood Risk Map project, China Research Institute of Water Resources and Hydropower set up a flood analysis software technology research and development team with core technical personnel in numerical modeling. Many research teams integrated domestic advantages of model technology, them include the research team of China Research Institute of Water Resources and Hydropower, Hohai University, Nanjing Research Institute of Water Resources, Shandong University and other research, etc. The basic modules include a one-dimensional river network calculation engine for scheduling simulation of complex water conservancy projects, a high-resolution two-dimensional flood analysis calculation engine, a drainage network model engine and a fast unstructured grid generation module, as shown in Figure S1. The model also realizes the coupling between river network and two-dimensional surface and the coupling between urban pipe network and two-dimensional surface model. Besides, based on the self-developed GIS platform, the model completed the integration and development of the pre- and post-processing of one-dimensional and two-dimensional flood model and urban pipe network model. The model was officially released and applied in October 2015. The model provides technical support for small and medium-sized rivers, flood protection areas, flood storage and detention areas and Urban flood risk analysis, which is called flood analysis software IFMS/Urban. The model interface is shown in Figure S2, and the dynamic simulation diagram of the model is shown in Figure S3.

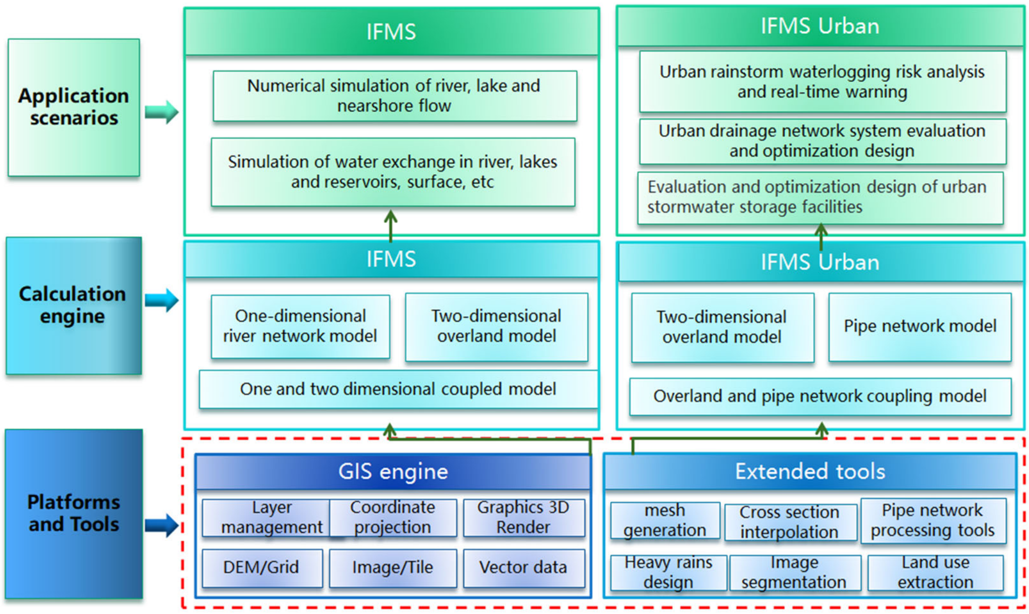

Figure S1. Framework diagram of the model.

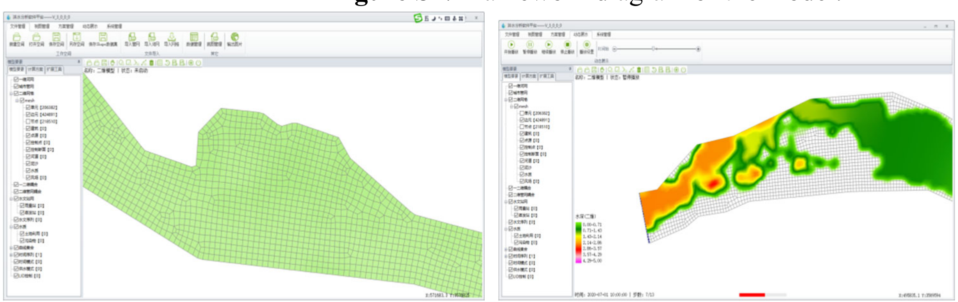

Figure S2. Model interface.

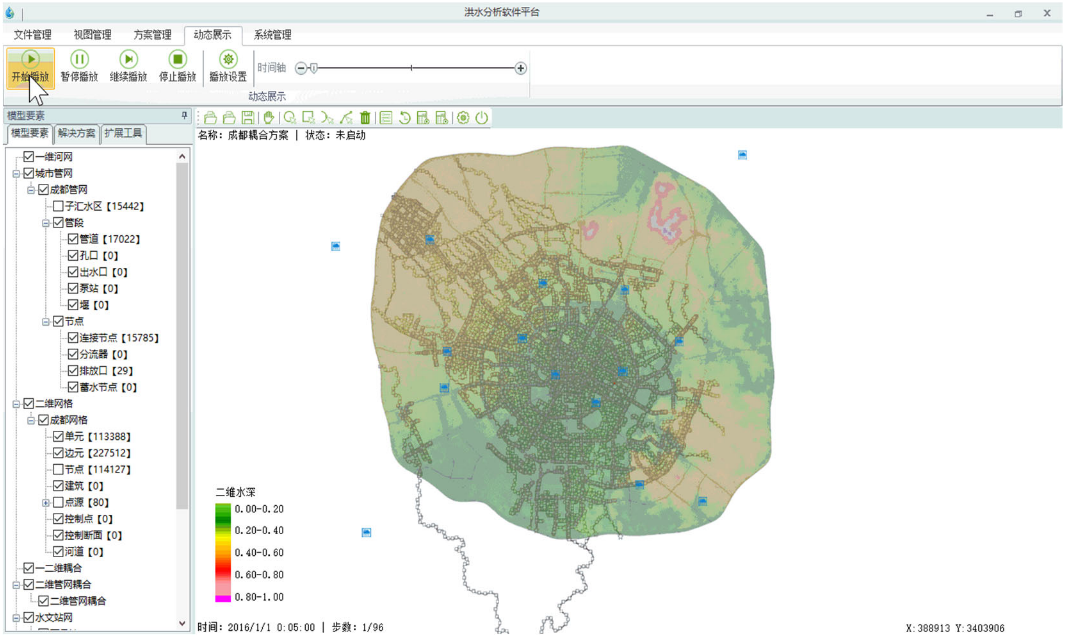

Figure S3. Dynamic simulation diagram of the model.

(2) Algorithm of IFMS/Urban model

a、2D overland model

The basic principle of the 2D model is to use the finite volume method based on unstructured grid to discretely solve the 2D unsteady flow governing equation. The Godunov scheme based on the finite-volume method is used to discretize the equations. The 2D model uses the Roe's approximate Riemann solver in the calculation of flow flux. The bed slope source term is discretized by feature classification to ensure the conservation of the model, and friction source term is discretized by implicit treatment to improve the stability of the model. The MUSCL format and the Runge-Kutta approach are also applied to achieve second-order accuracy in space and time. This method is suitable for models with complex terrain and large water discontinuities, which have been tested with a classical numerical case [33-35].

b、1D pipe network model

The sewer flow is modeled in this study with a revised version of the open-source code of the SWMM engine.

c、Models' coupling

To realize the flow exchange between the surface runoff and drainage network flows, it is put forward the overflow and backflow at the sewer system nodes (catch-basins and manholes, etc.)[36]. The interaction between the surface runoff and drainage network flows is shown in Figure S4(a)-(b). Z_{nw} is the water level inside the drainage network nodes and Z_{sw} the water level of surface runoff.

When $Z_{\text{nw}} > Z_{\text{sw}}$, there would be overflow at the drainage network node. The interaction flow was approximately equal to the overflowing quantity calculated based on the sewer system, $Q_{\text{int}} = Q_{over}$;

When $Z_{\text{nw}} < Z_{\text{sw}}$, there would be backflow at the drainage network node. The interaction flow was calculated using the empirical weir formula.

$$Q_{\text{int}} = Q_{back} = \begin{cases} m_1 \varepsilon C h_s (2 g h_s)^{0.5}, h_n / h_s \le 2/3 \\ m_2 \varepsilon C h_n \left[2g(h_s - h_n)\right]^{0.5}, 2/3 < h_n / h_s \le 1 \end{cases} \quad (1)$$

In the formula, m_1 and m_2 are the flow coefficients, and ε is the contraction coefficient, which is determined by the shape of the rain gates, C is the width of the rain gates, $h_s = Z_{sw} - Z_{nu}$, $h_n = Z_{nw} - Z_{nu}$, and Z_{nu} is the top elevated level of the rain gates.

When $Z_{nw} \approx Z_{sw}$ or $Z_{nw} << Z_{sw}$, there would be no flow interaction between the surface runoff and the flood at the drainage network nodes.

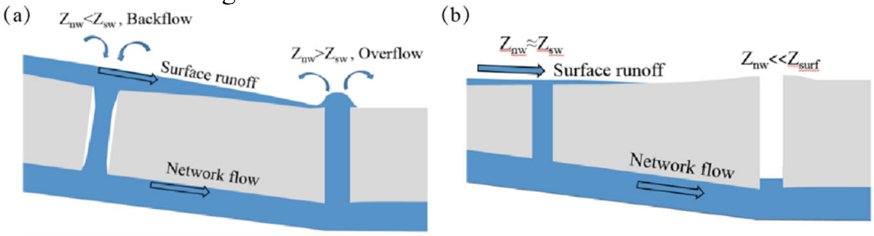

Figure S4. Diagram of flow interaction. (**a**) Overflow and backflow; (**b**)No flow interaction

(3) Part application of IFMS/Urban model.

The model has been tested in a number of urban flooding simulation programs including Chengdu, Zhengzhou, Jinan, etc., as shown in below Figures S5-S7.

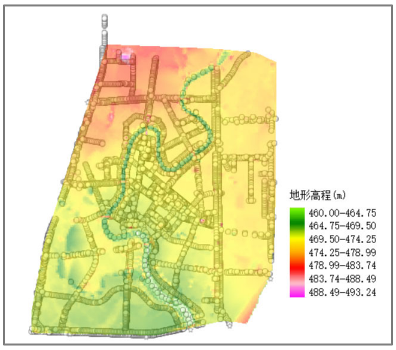

Figure S5. River network and two-dimensional surface coupling model of a district in Chengdu.

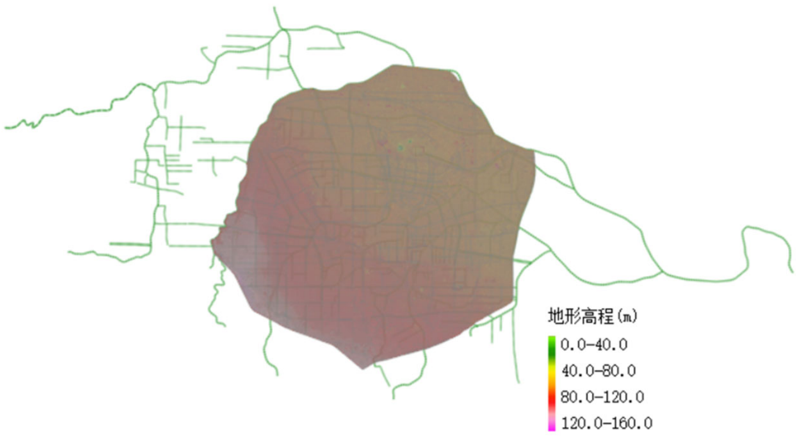

Figure S6. River network and two-dimensional surface coupling model of a district in Zhengzhou.

Figure S7. River network and two-dimensional surface coupling model of a district in Jinan.

(4) Achievement of IFMS/Urban model

In order to support the flood risk mapping project in key regions of China, IWHR has led the development of the first universal flood analysis software IFMS/Urban. The software can be applied to almost all types of flood simulations in China, and has been selected as one of 60 outstanding achievements (products) of IWHR. The model has won the second prize of National Science and Technology Progress Award and the first prize of provincial and ministerial level. It has obtained 6 national invention patents, 4 appearance patents, and 4 software copyrights. Besides, there are many related papers published using this software.

2. Model building process

In this research, the flood in urban drainage networks was simulated using the 1D hydrodynamic model, and the surface runoff was simulated by 2D overland model. The flow exchange between the surface runoff and drainage network flows was calculated by eq.(1).

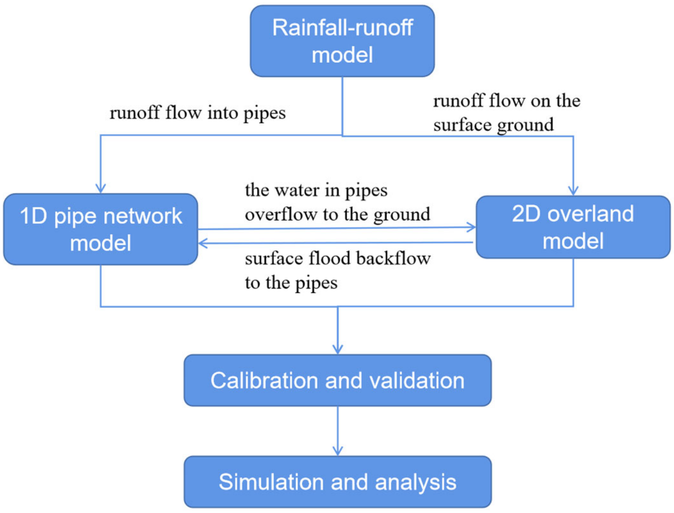

Figure S8. Overview of technical research approach.

(1) Rainfall-runoff model

There are some areas without pipe network data in the research area. For areas with drainage pipe network distribution, the rainfall runoff is calculated by sub-catchment; while in areas without drainage pipe network, a two-dimensional model grid is used to calculate the surface runoff. Unlike watersheds, urban areas also have many roads, buildings and other facilities that affect the flood intrusion. Therefore, in the actual process of dividing the sub-catchment area, the study area was divided into 1494 sub-catchment areas based on topography, roads, buildings, LID measures and other factors, as shown in figure S8. Based on the DEM, ArcGIS software was used to analyze slope gradient, as shown in Figure S9. In this paper, Horton-infiltration formula was used to calculate the infiltration of pervious areas.

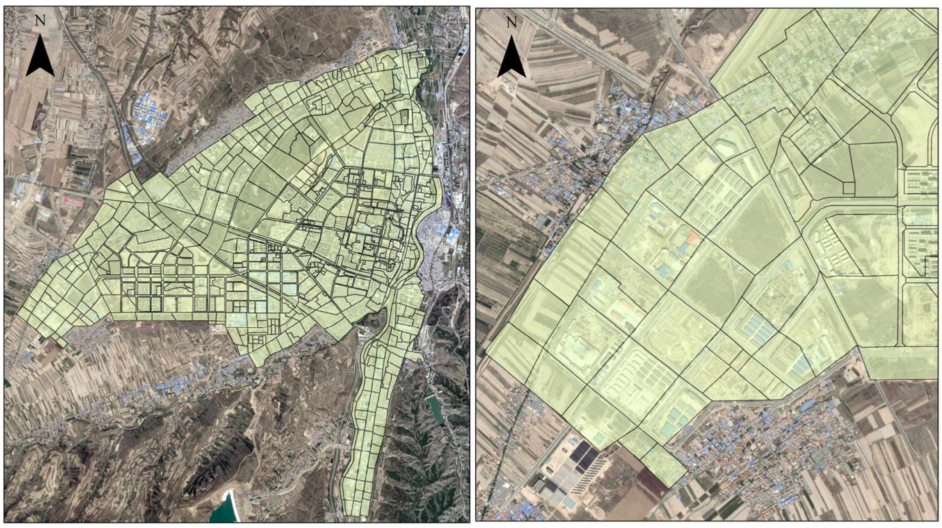

Figure S9. The sub-catchment area. (a) All sub-catchment areas; (b) Local sub-catchment area.

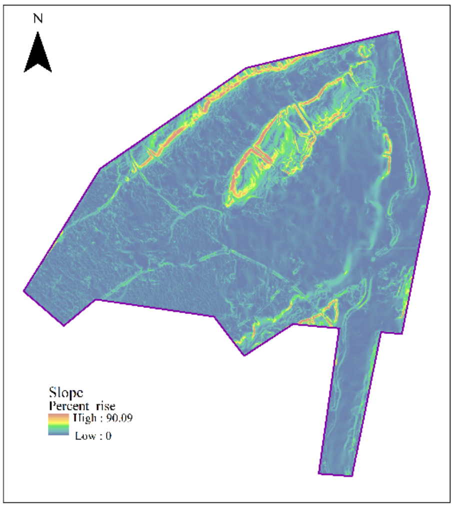

Figure S10. Slope gradient.

(2) 1D and 2D coupled model

Before the 1D pipe network model is constructed, the collected pipe network data should be processed first. This includes checking the topology of the pipe network, combining short pipes, and deleting duplicate nodes. After processing, there are a total of 4,623 pipes with a total length of 208.027 km and 4512 nodes. The diameter of the pipes is about 0.2-2.2m, with a total of 32 discharge outlets according to field survey.

Secondly, grid subdivision was carried out. The external constraint of the grid is the research scope, and the internal constraint is the roads and buildings in the urban area. And there is a total of 115 thousand of unstructured grid in research areas. The resolution of the grid is about 15-20m. Based on the DEM and land use data, the elevation and roughness of each grid is assigned.

Finally, 1D model and 2D model were coupled by nodes to realize the simulation of water flow exchange between surface ground and drainage pipe networks.

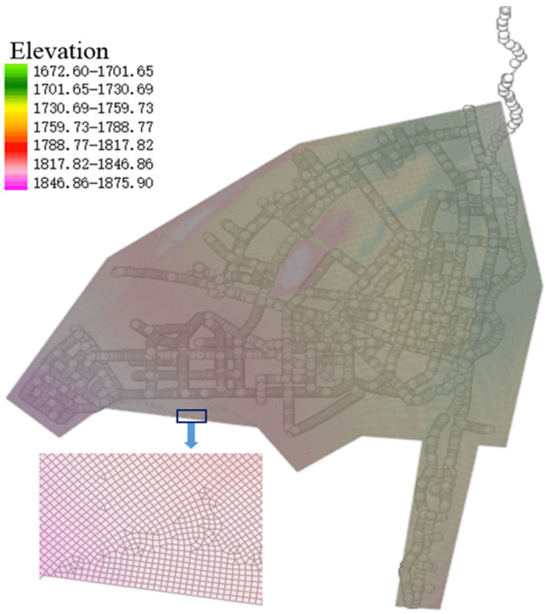

Figure S11. The coupled 1D and 2D hydrodynamic model of the study area.