A large-scale waterlogging investigation in highly urban area of Beijing

Lu Liu

Development Research Center, Ministry of Water Resources

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XVIII WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature

第18届
世界水资源大会
水与万物:
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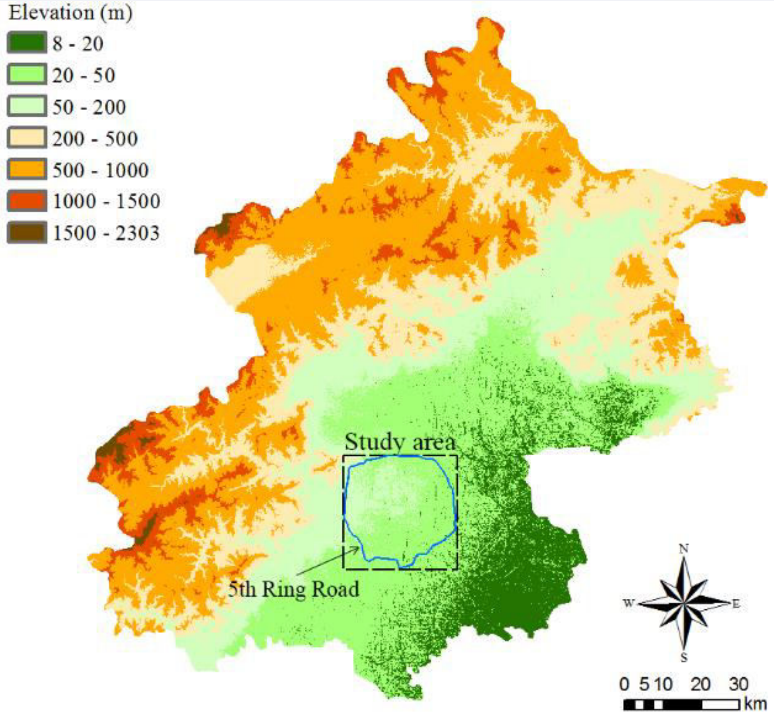
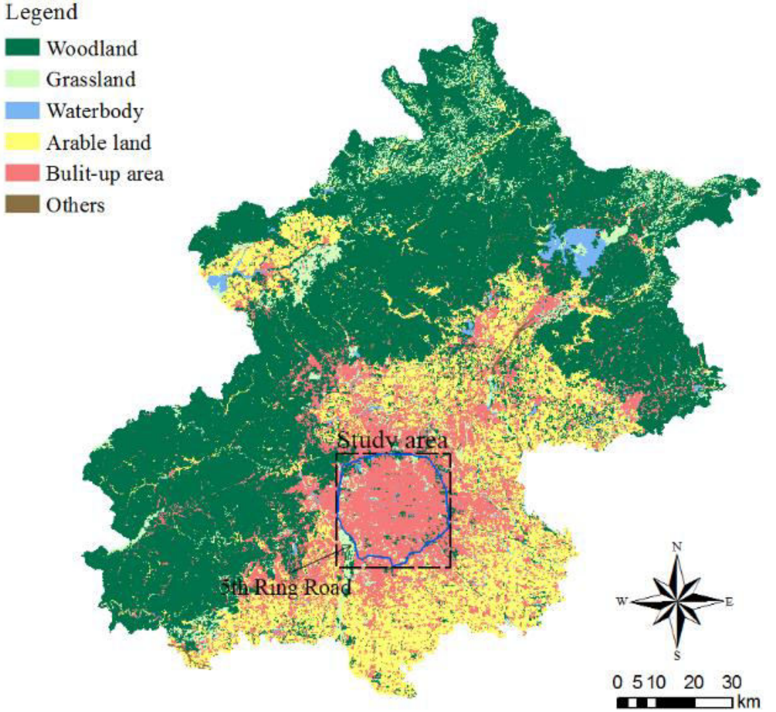
Study Area



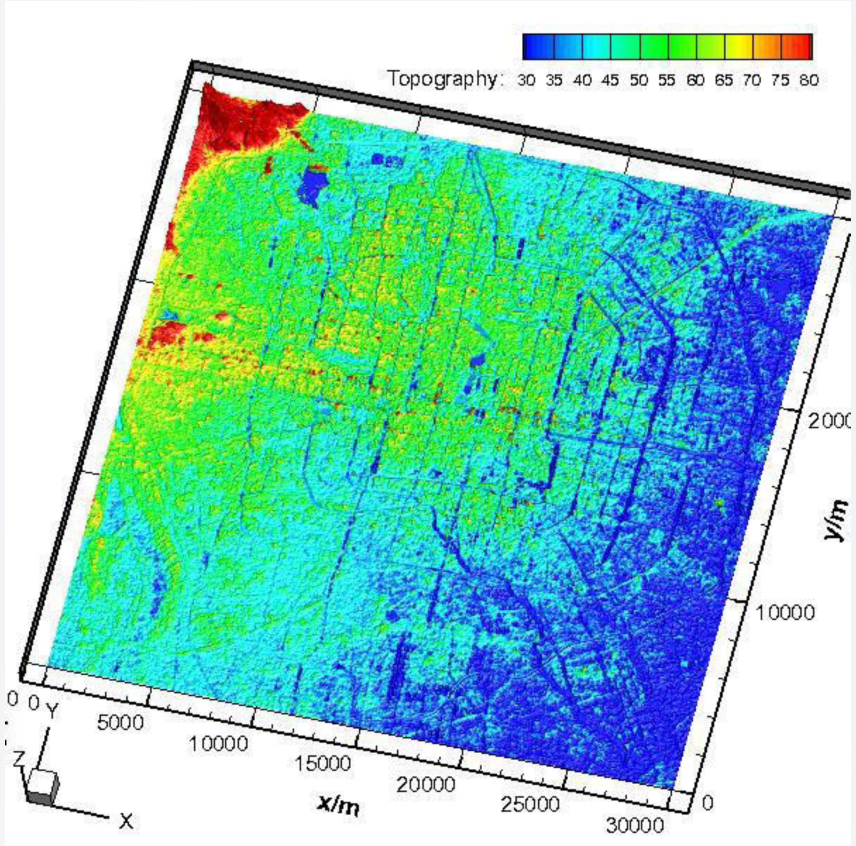
(a) Digital Elevation Model (DEM) of Beijing

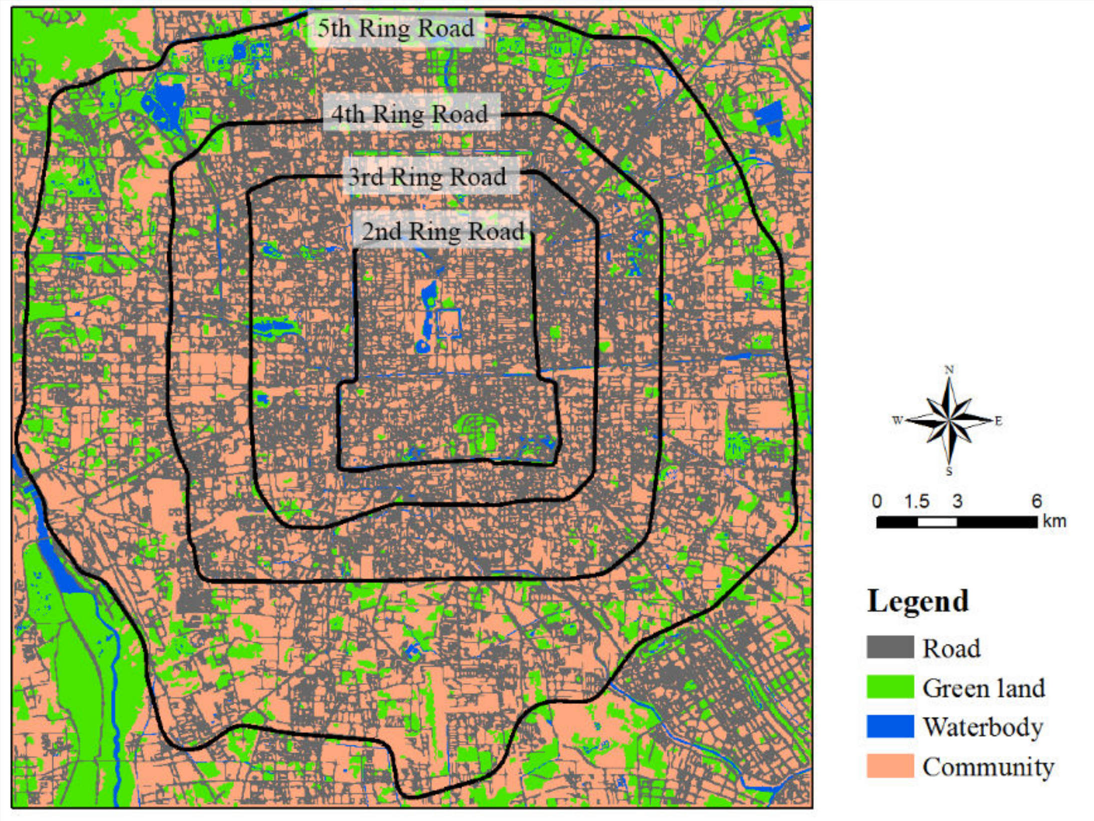


(b) Land cover of Beijing

- The highly urbanized region of Beijing, especially the region within the Fifth Ring Road, is considered as the most vulnerable area to flooding
- In the current study a 30 km x 30 km urban region, covering the Fifth Ring Road and inside area, is chosen as the study site.

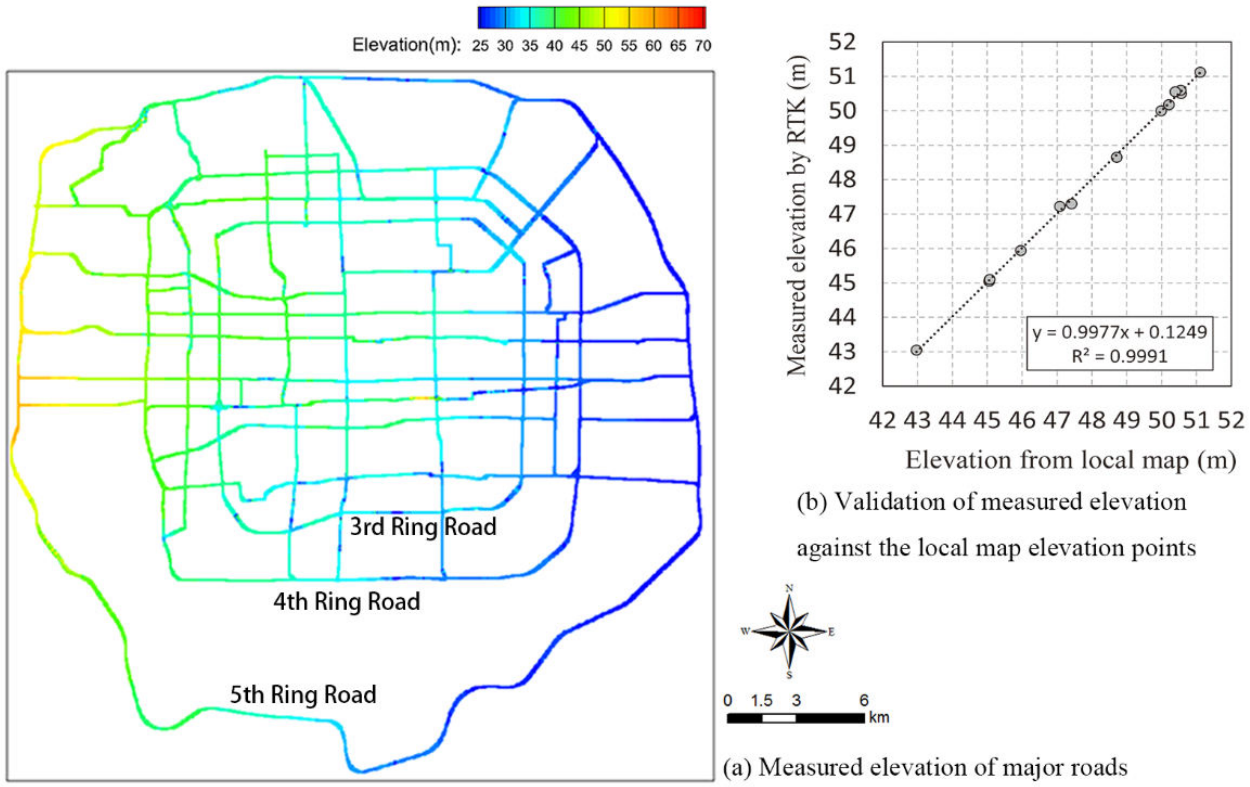
Data availability and processing





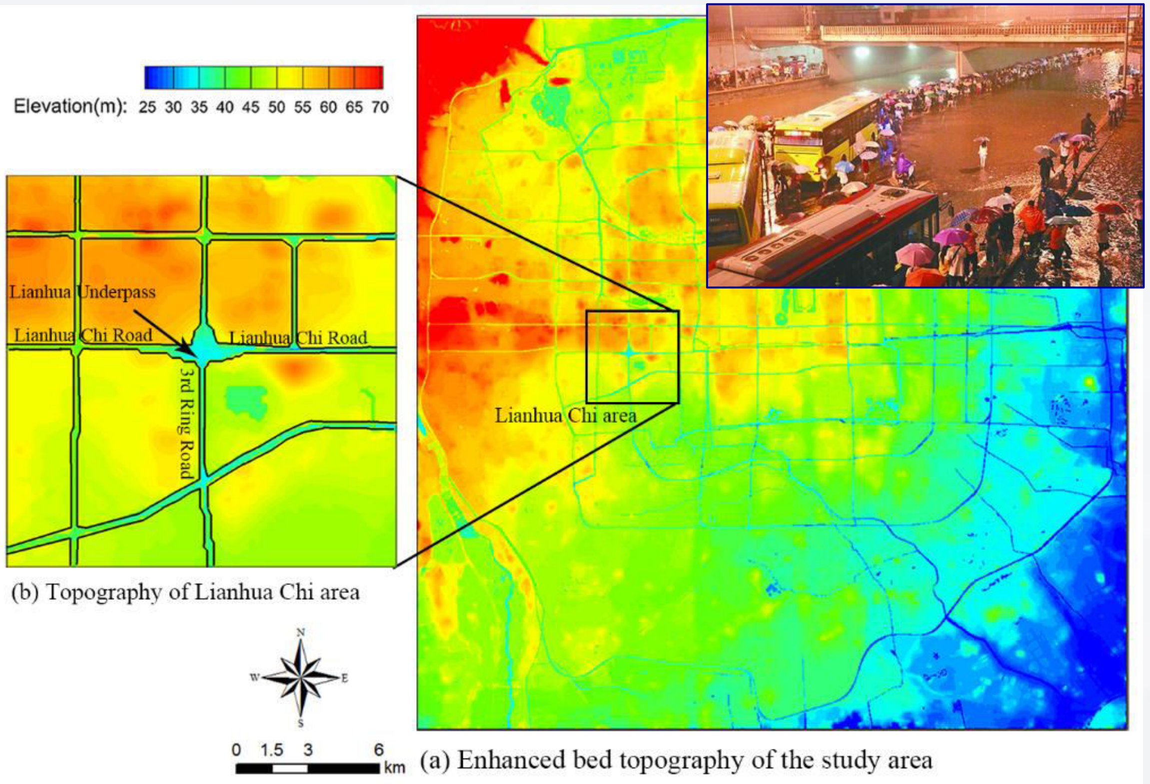
- Filling and breaching approaches were applied to remove spurious features in 30 m DEM.
- Extra processes for road extraction were conducted to characterize potential water accumulation points (ponds) and flow paths.
- GIS-based road network data were initially inserted into DEM data, and road elevations were assumed to be 0.2 m lower than the pavement based on field measurements and road section design in Northern China.

Topography data



(b) Validation of measured elevation against the local map elevation points

(a) Measured elevation of major roads



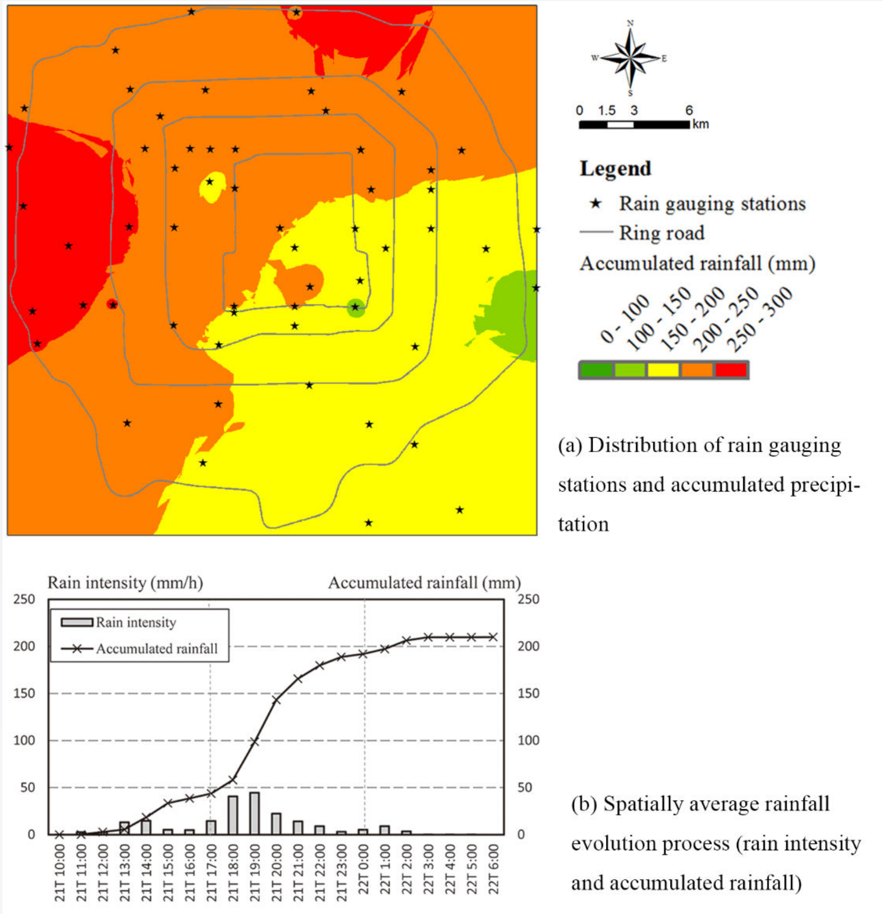
(b) Topography of Lianhua Chi area

(a) Enhanced bed topography of the study area

The main roads in the study area, including the 2nd to 5th Ring Roads and the other major roads connecting with them.

A typical waterlogging site (Lianhua Chi area) located in an underpass area of the Third Ring Road is shown.

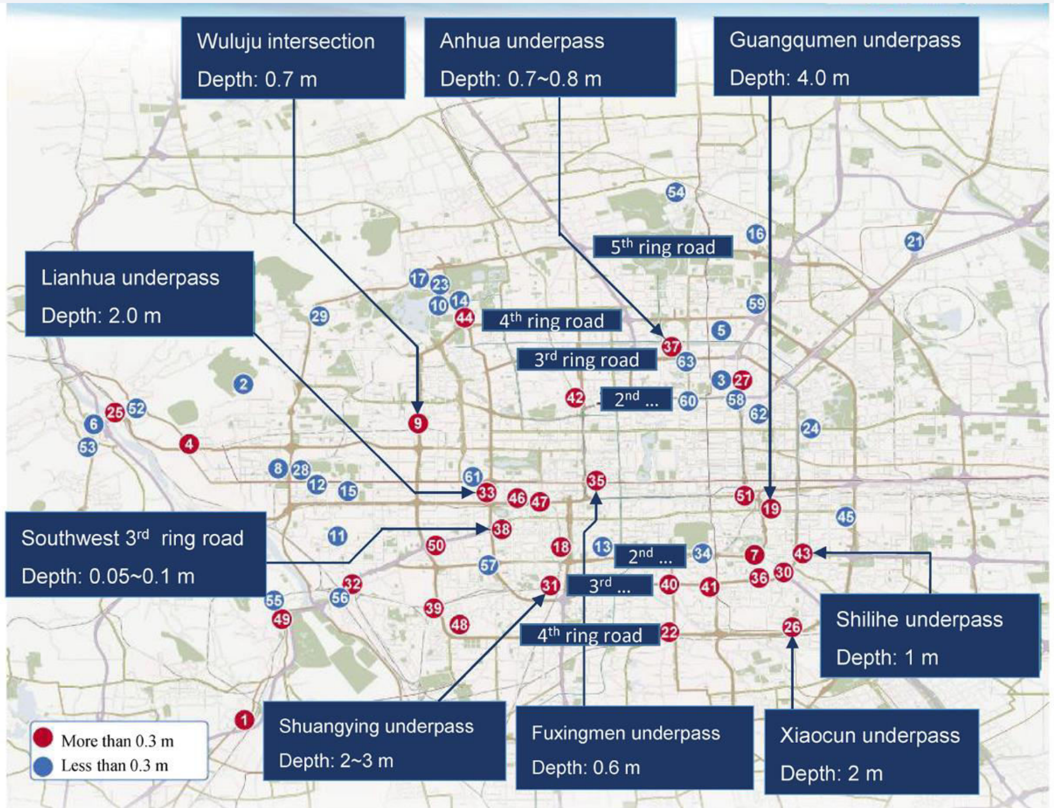
Rainfall Data and Observed Waterlogging



(a) Distribution of rain gauging stations and accumulated precipitation

(b) Spatially average rainfall evolution process (rain intensity and accumulated rainfall)

An extreme storm event during 21st and 22nd July is investigated.
On average, the accumulated rainfall reached 210 mm.



In total 51 seriously affected waterlogging sites were found, with most of them being located at road underpasses and intersections. About 55% of waterlogging sites occurred within the Third Ring Road.

Flood inundation modelling

- Governing equations: two-dimensional Shallow Water Equations (SWEs).
  - Continuity equation

$$\frac{\partial \eta}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = R - f - d$$

  - Momentum equations

$$\frac{\partial q_x}{\partial t} + \frac{\partial\left(\beta q_x^2 / H\right)}{\partial x} + \frac{\partial\left(\beta q_x q_y / H\right)}{\partial y} = -gH\frac{\partial \eta}{\partial x} - \frac{g q_x \sqrt{q_x^2 + q_y^2}}{H^2 C^2} + \nu\left[2\frac{\partial^2 q_x}{\partial x^2} + \frac{\partial^2 q_x}{\partial y^2} + \frac{\partial^2 q_y}{\partial x \partial y}\right]$$

$$\frac{\partial q_y}{\partial t} + \frac{\partial\left(\beta q_x q_y / H\right)}{\partial x} + \frac{\partial\left(\beta q_y^2 / H\right)}{\partial y} = -gH\frac{\partial \eta}{\partial y} - \frac{g q_y \sqrt{q_x^2 + q_y^2}}{H^2 C^2} + \nu\left[\frac{\partial^2 q_y}{\partial x^2} + 2\frac{\partial^2 q_y}{\partial y^2} + \frac{\partial^2 q_x}{\partial x \partial y}\right]$$

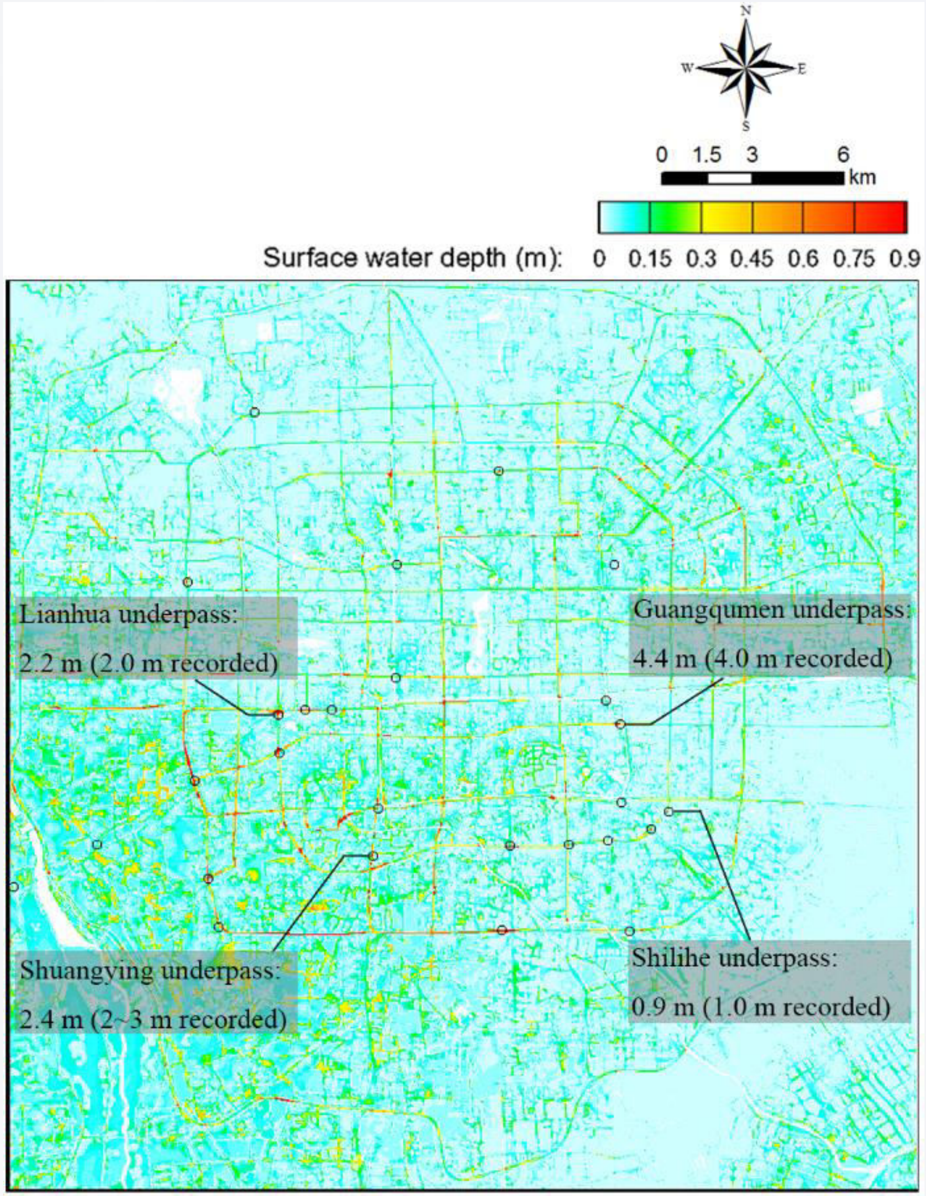
supercritical flows

subcritical flows

- The SWEs are used to predict the water elevation and velocity distributions in urban flood flows.

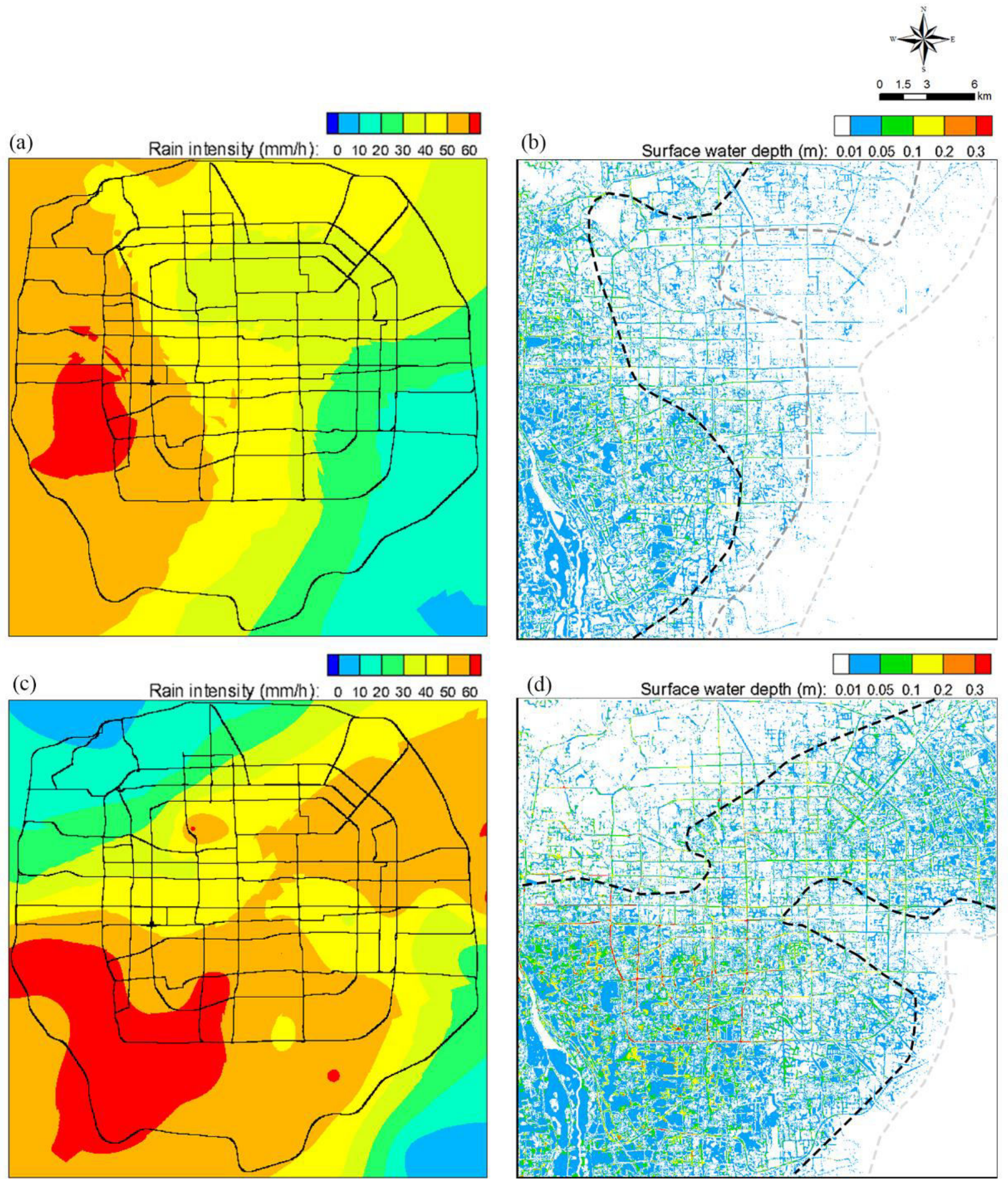
- A TVD-MacCormack scheme is used, which applies to both subcritical and supercritical flows.

Results



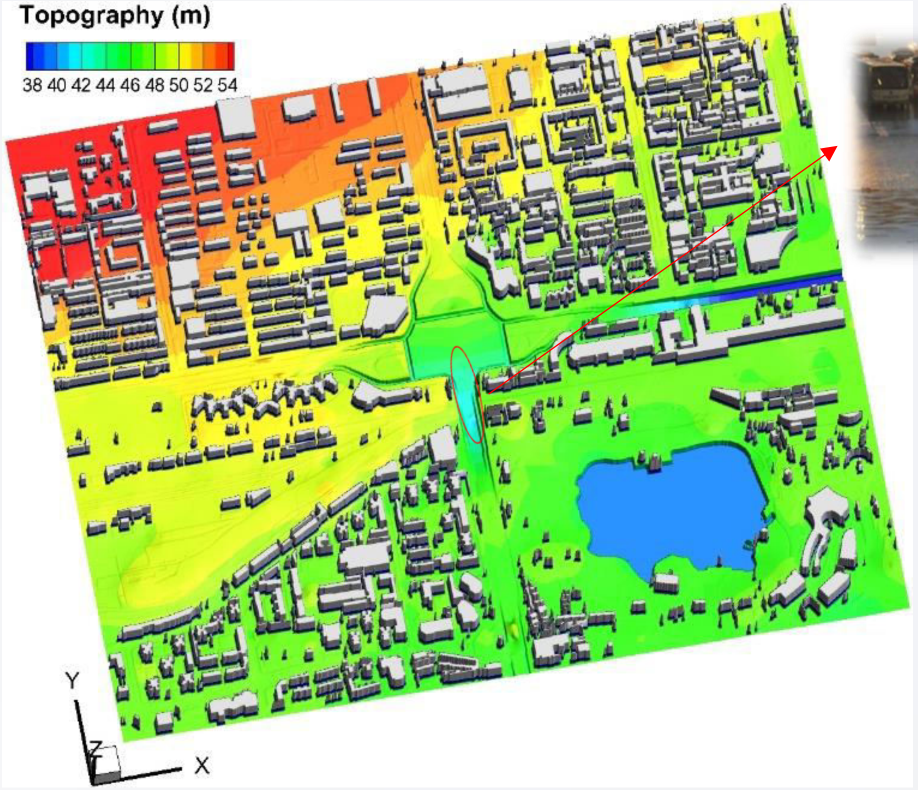
- The waterlogging sites were primarily located on the main roads, including underpasses, intersections and depressed sections.
- The numerical model correctively predicted more than 0.3 m depth at 72% of the reported sites within the Fourth Ring Road.

Heavy rainfall process and overland flow

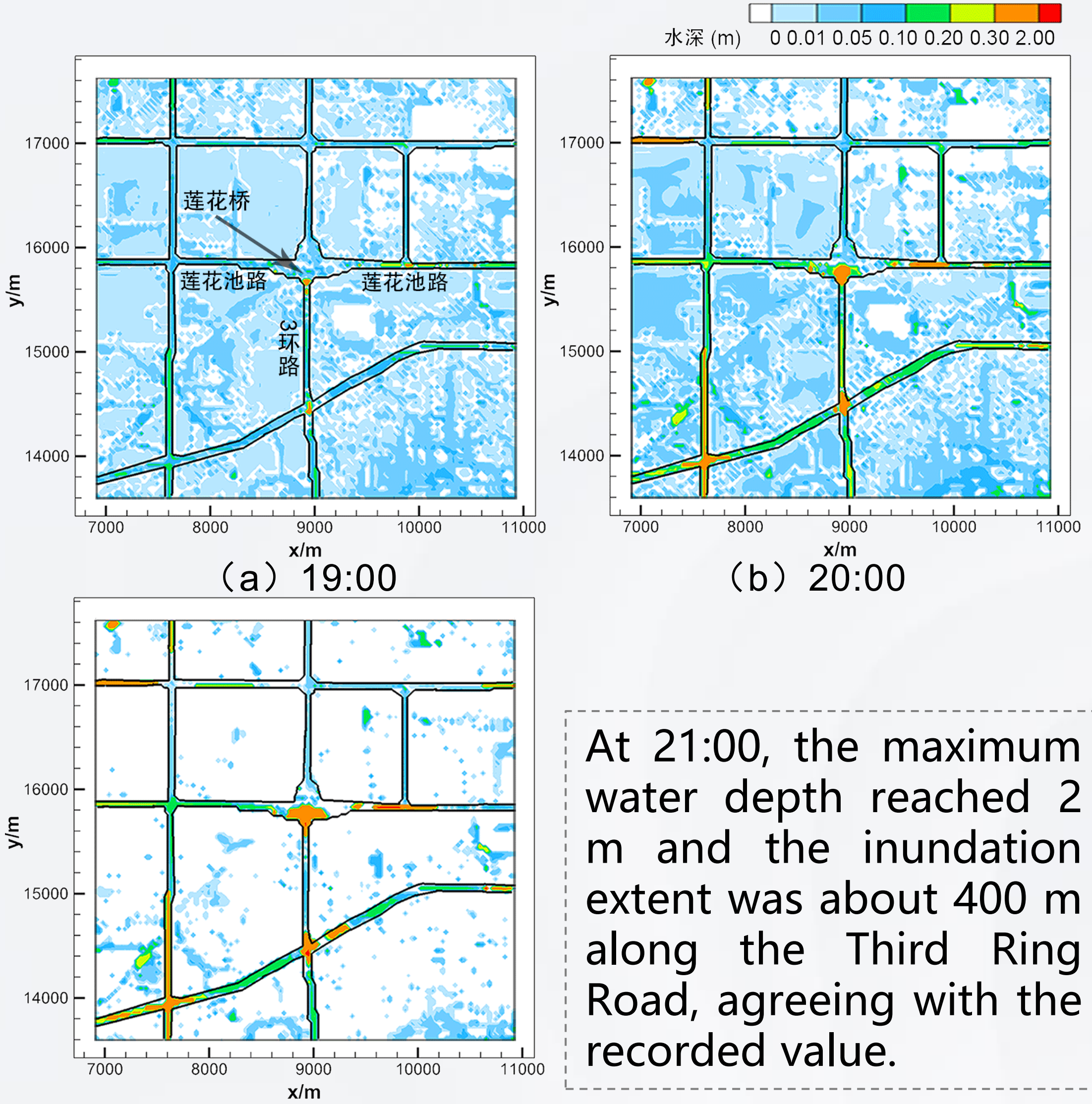


- In the north-eastern and south-western areas, where the rainfall intensity was over 50 mm/h, community areas were flooded.
- The spatial distribution of the surface water depth was similar to the distribution of the rainfall.
- Although the bed level reduced towards the east region, surface water movement to the east was not obvious.

Heavy rainfall process and overland flow



Lianhua Underpass was located under the intersection between the Third Ring Road and Lianhua Chi Road. The area was reported to be flooded with more than 2 m of water during the storm peak.

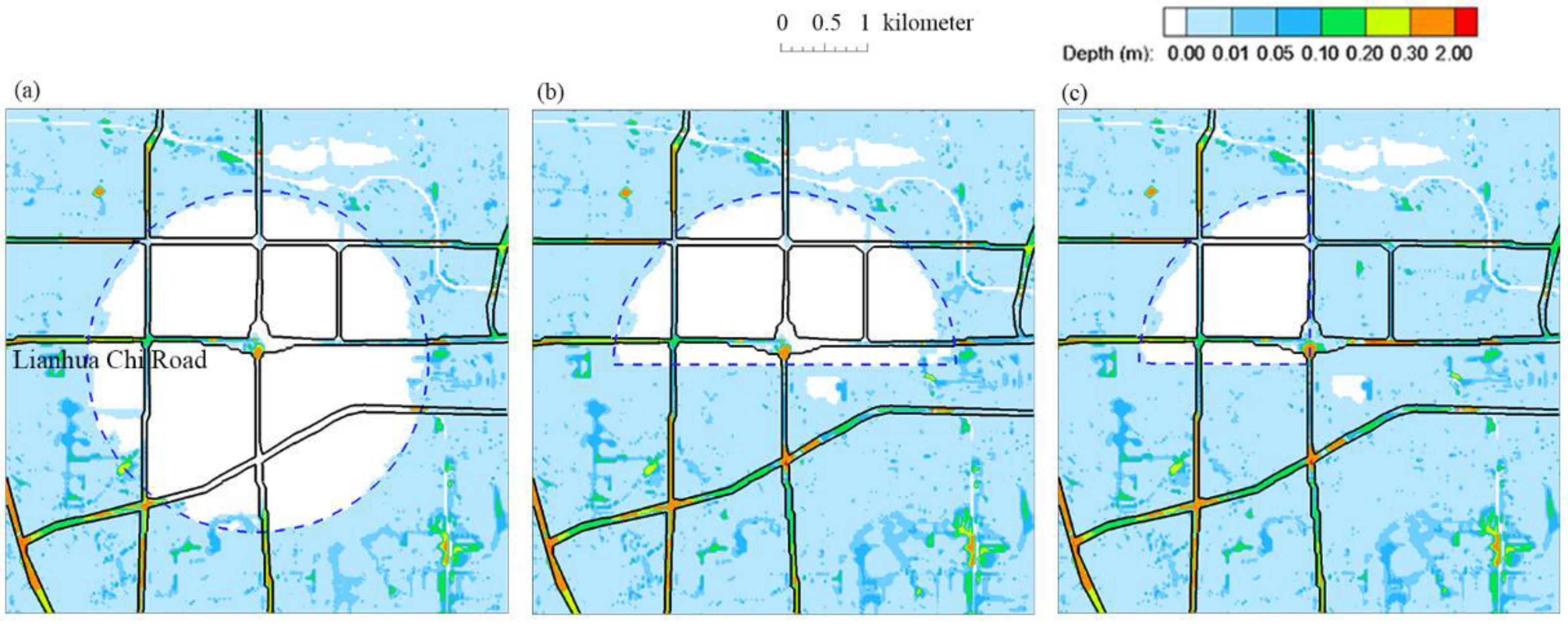


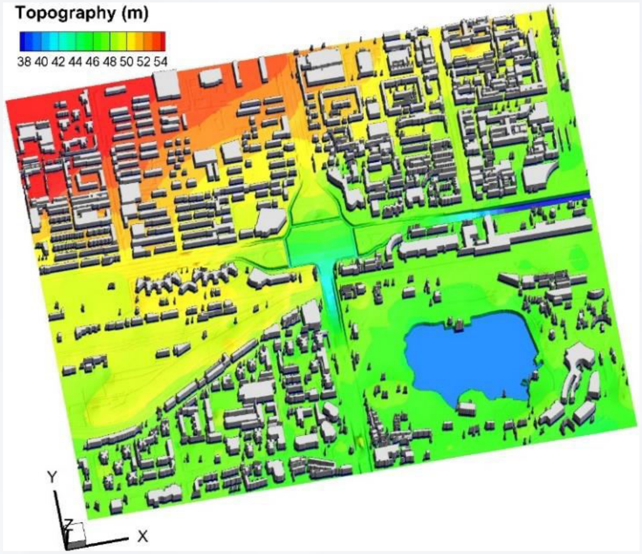
（a）19:00 （b）20:00 （c）21:00

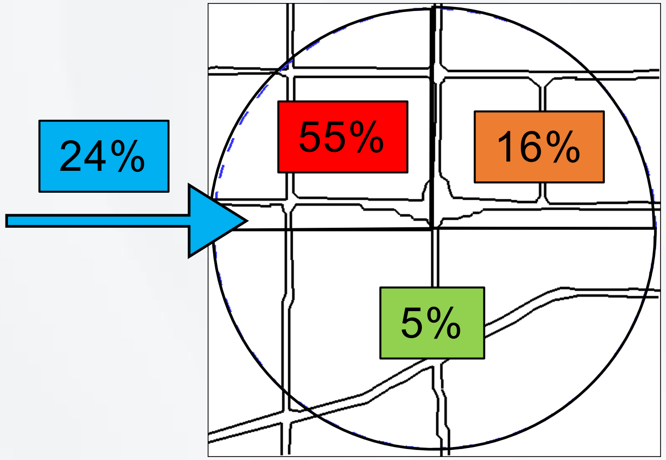
At 21:00, the maximum water depth reached 2 m and the inundation extent was about 400 m along the Third Ring Road, agreeing with the recorded value.

Heavy rainfall process and overland flow

To figure out the main source of the water accumulated in the area of Lianhua Underpass, three scenario simulations were conducted. In these scenarios the rainfall intensity, drainage capacity and infiltration were all set to zero within: (a) a circular area of 2 km radius; (b) the top half of the circular area; (c) the left half of the top half area.

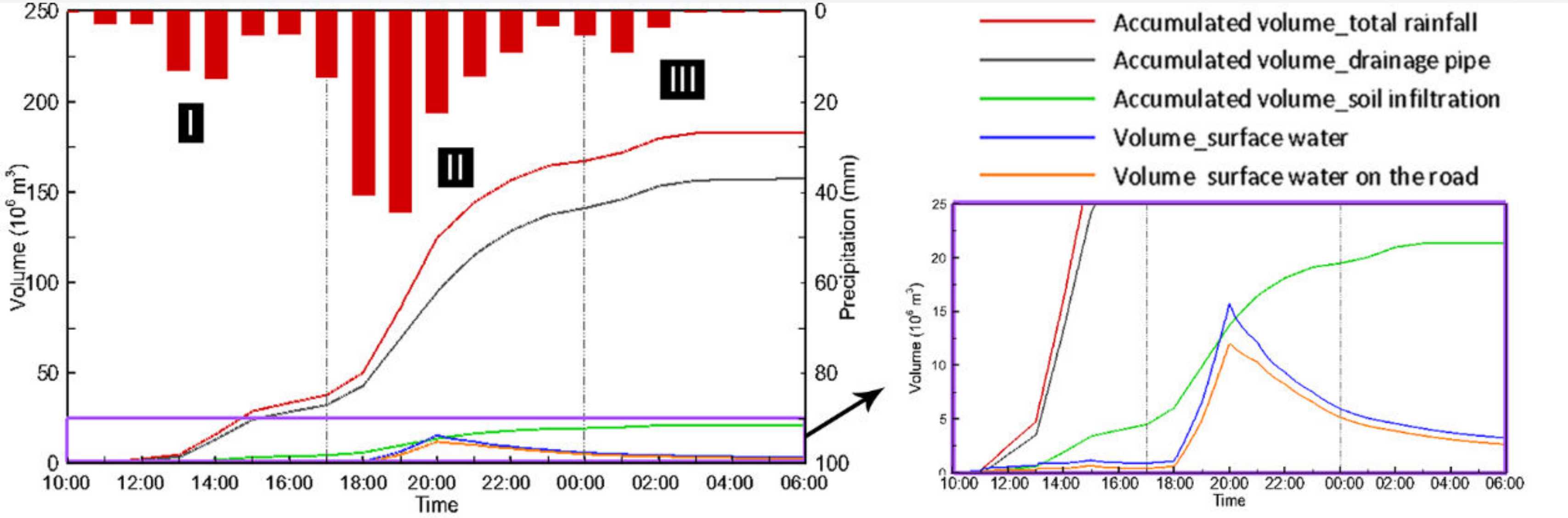




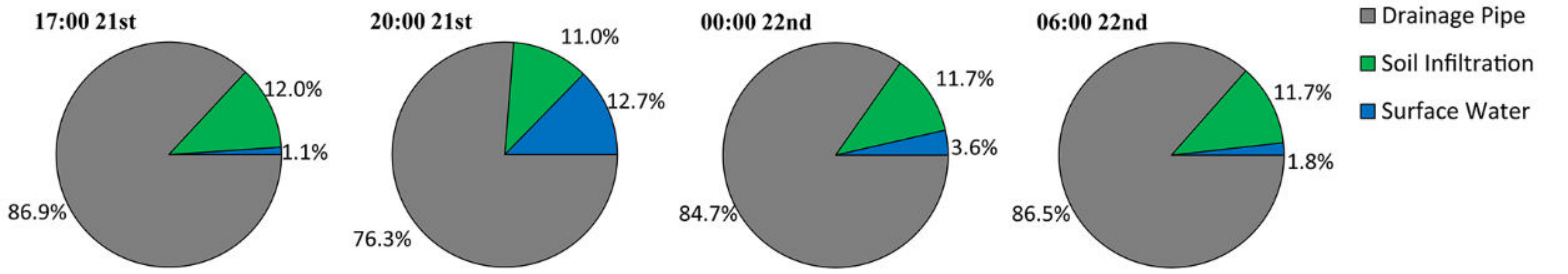


The majority of water in the underpass area of Lianhua was from the northwestern area, in agreement with topography, that overland flow was expected to flow towards southeast.

Statistical analysis



(a) Accumulated water volumes for total rainfall, drainage, infiltration, total surface water and surface water on the road.



(b) Distributions of water volumes at 17:00 21st, 20:00 21st, 00:00 22nd and 06:00 22nd.

- Around 3.6 % of the total volume was on the ground surface at the end of heavy rainfall period (00:00 22nd).
- At the end of the rainfall event (06:00 22nd), around 86.5% of rain water was drained into drainage systems.
- Infiltration losses were limited to be about 11.7% of total volume at the end of the rainfall process.

Conclusions

- The drainage system in the urban area of Beijing was shown to be generally efficient under the very heavy July 2012 rainfall. When the rainfall intensity reached the peak (19:00 to 20:00 21st), 12.7% of the total volume remained on the ground surface. The large volume of rain water was quickly taken by the drainage system, rivers and infiltration, with around 3.6 % of the total volume being on the ground surface at the end of heavy rainfall period (00:00 22nd).

- Complex road networks not only played an important role in surface runoff conveyance, but they also imposed more stress to the drainage systems. Waterlogging sites were usually located in depression points of main roads, such as underpasses and intersections, in the highly urban area, where the population density is very high.

- The waterlogging sites were associated with local bed topography and rainfall intensity. Rainwater moving through the surrounding community areas and roads contributed predominantly to the formation of waterlogging, while rainwater gathering from over 2 km distance was limited.