One Map to Manage Risk, One Standard to Protect Underground Spaces[1]

Shenzhen's Innovative Practices in Preventing and Managing Urban Flooding in High-Density Built-Up Areas under Extreme Rainfall

Abstract: As global climate change makes extreme rainstorms more frequent and intense, urban flooding poses a particularly serious risk to high-density built-up areas with concentrated populations and assets and extensive underground development. It has become a major safety challenge shared by large cities worldwide. On 7 September 2023, Shenzhen experienced an exceptionally severe rainstorm, with seven meteorological indicators exceeding historical records. Five major river sections overflowed, and 155 buildings and underground spaces were flooded, causing temporary service suspensions on several metro lines and localized disruptions to critical urban lifeline infrastructure. The event exposed insufficient resilience at vulnerable points in the city, particularly underground spaces, when rainfall exceeds design standards. In response, Shenzhen pursued coordinated, system-wide measures covering engineering standards, basin-wide coordination and institutional development. It developed a unified Pluvial Flood Risk Map, making risk levels a mandatory consideration before infrastructure siting and underground space development; issued China's first local standard specifically addressing flooding prevention in urban underground spaces, establishing differentiated protection requirements across facility categories and risk levels, from planning and construction to operation, maintenance and emergency response; and strengthened basin-wide coordination of flood control and drainage, promoting compatible river flood-conveyance standards across administrative boundaries. Digital technologies also helped enhance forecasting, early warning, scenario simulation and contingency planning. Shenzhen's innovations offer useful lessons for megacities and other very large cities seeking to improve urban flood prevention and management and strengthen climate resilience.

Keywords: extreme rainstorms; urban flooding; underground space waterlogging prevention; engineering standards; climate resilience

I. Background

Global climate change is increasing the frequency and intensity of extreme precipitation events. China is among the world's most climate-sensitive and severely affected regions. According to the Blue Book on Climate Change in China (2025), the annual cumulative number of heavy-rain days in China increased by an average of 4.5% per decade between 1961 and 2024. The national climate risk index reached its highest level since 1961 in 2024, with flood risk particularly pronounced. Extreme rainstorms, including the "20 July" event in Zhengzhou and the July 2023 event in the Beijing–Tianjin–Hebei region, have caused major urban flood losses, exposing common weaknesses in flood prevention systems in high-density built-up areas. The 2025 Central City Work Conference identified "building safe, reliable and resilient cities" as a priority for urban development. Preventing and managing urban flooding under extreme rainfall has therefore become an urgent nationwide challenge.

[1] Case provided by CCICED Scoping Study on *Building a Climate-Adaptive Society*

Located in the Pearl River Delta, Shenzhen provides a representative case of this nationwide challenge. With a total area of 1,997.47 km², Shenzhen is a prototypical high-density megacity. The proportion of the city's area covered by impervious built-up surfaces has risen from approximately 4.2% in 1990 to around 50% today. Population and economic activity are highly concentrated, with a population density of 9,000 people/km² and an economic density of approximately RMB 2.7 billion/km².

From 7th to 8th September 2023, Shenzhen experienced record-breaking extreme rainfall (hereinafter referred to as the "9.7" rainstorm) triggered by the combined influence of the remnant circulation of Typhoon Haikui, the monsoon and a weak cold air mass. The intense rainfall lasted nearly 21 hours, with the average accumulated rainfall across the city reaching 281.7 mm. All eight administrative districts simultaneously registered rainfall at the "extreme rainstorm" level. The average accumulated rainfall in Luohu District reached 466.2 mm, while the maximum recorded 72-hour rainfall total was 619.0 mm. The event broke seven meteorological records in Shenzhen's observation history, which dates back to 1952. Water levels exceeded flood-control limits at 24 reservoirs and warning levels at 58 river gauging stations. Five major river sections overflowed, and 155 buildings and underground spaces were flooded. The operation of lifeline infrastructure, including water and power supply systems, was disrupted at multiple locations.

These challenges exposed during the rainstorm are not unique to Shenzhen. In terms of risk, its dense population and extensive concentrations of rail transit, underground commercial spaces and lifeline infrastructure reflect the high exposure and vulnerability of high-density megacities worldwide. In terms of natural landscape and hydrological conditions, its hilly terrain, short rivers with steep upstream and gentle downstream gradients, and tidal backwater effects exemplify the compound risks faced by coastal and estuarine cities when river flooding, urban surface-water flooding and high tides may occur simultaneously. In terms of governance, inadequate drainage standards in older built-up areas and incompatible river improvement standards across administrative boundaries are legacies of rapid urbanization found in many places. Shenzhen's experience offers useful lessons for established high-density cities in China and worldwide, as well as cities in developing countries facing the combined pressures of rapid urbanization and increasing extreme rainfall risk.

Problem 1: Lack of unified and systematic technical standards for underground space waterlogging prevention.

The majority of inundated underground spaces in Shenzhen were residential underground parking garages, but metro stations, commercial underground complexes, and other critical public facilities were also affected. Within the existing planning, construction, and management framework, no unified technical specification existed to govern the setting of waterlogging prevention standards, risk assessment, engineering measures, and emergency management for underground spaces. Requirements for the construction, operation and maintenance control of different types of underground spaces varied significantly, resulting in inadequate systemic waterlogging prevention performance.

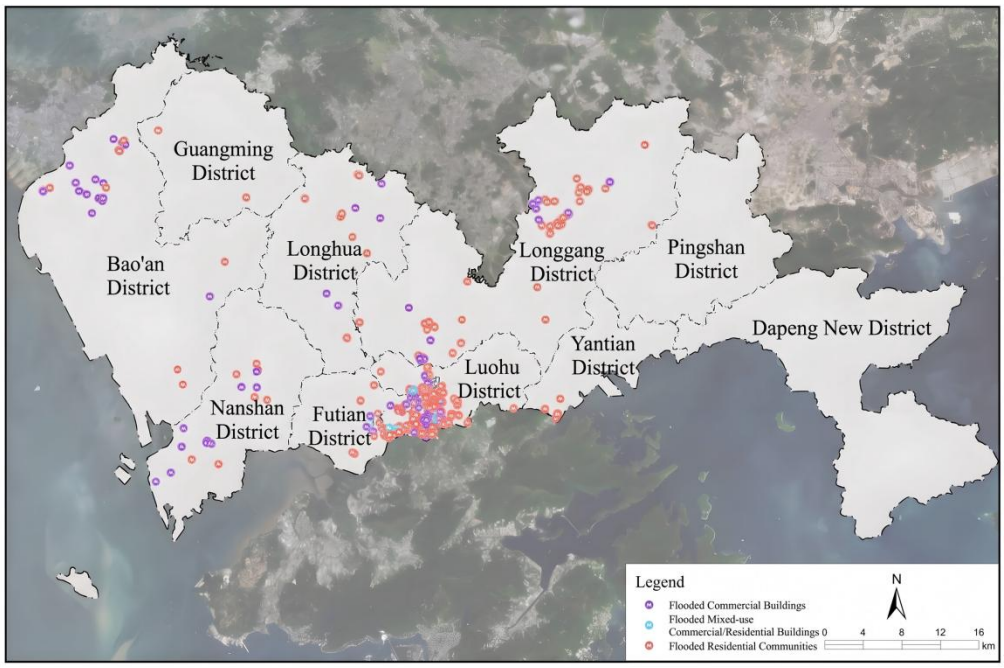

Figure 1. Distribution of buildings flooded during the 2023 "9.7" extreme rainstorm in Shenzhen

Problem 2: Insufficient waterlogging resilience of vulnerable urban nodes.

Based on an analysis of the "9.7" rainstorm scenario, a number of lifeline infrastructure facilities, hospitals, schools, and other essential installations in Shenzhen were found to be located in medium- and high-risk waterlogging zones. The integration of urban infrastructure siting with waterlogging risk assessment remained insufficiently coordinated, and significant waterlogging prevention weaknesses were evident at critical vulnerable nodes. There was an urgent need to systematically strengthen the city's overall waterlogging resilience.

Problem 3: Incompatible river management standards across administrative boundaries impair the basin-wide flood discharge capacity.

The Shenzhen River narrows sharply at the Luohu Port section, while high tides create backwater effects downstream. In the Longgang River basin, the downstream Danshui River in Huizhou was improved to a standard corresponding to a 30-year event, well below the 100-year-event standard of the upstream Longgang River in Shenzhen. This mismatch raises upstream water levels through backwater effects and exacerbates urban flooding.

Figure 2. Schematic map of inconsistent standards between upstream and downstream in the Longgang River basin

II. Key Measures

(1) Using the Pluvial Flood Risk Map to Guide Infrastructure Siting and Underground Space Development

To address the concentration of certain urban vulnerable nodes within medium- and high-risk flood zones, the Water Authority of Shenzhen Municipality, the Emergency Management Bureau of Shenzhen Municipality and other relevant departments developed a unified "Pluvial Flood Risk Map" as a key basis for planning flood control for urban underground spaces. Using observations from the "9.7" rainstorm and mathematical modelling, the city identified high-risk areas and established a risk register organised by facility type, covering metro systems, underground commercial spaces, lifeline infrastructure, hospitals and schools. Key facilities and underground spaces across the city were classified by type and by high-, medium- or low-risk. In high-risk zones, stringent controls require existing underground spaces and key infrastructure to undergo comprehensive, dedicated pluvial flood risk assessments and eliminate all major flood hazards. In medium-risk zones, the focus is on addressing weaknesses and upgrading facilities, optimising drainage networks and strengthening routine monitoring and early warning to improve local flood preparedness. In low-risk zones, routine management and preventive measures maintain a basic level of flood control.

(2) Issuing China's First Technical Standard for Flooding Prevention in Urban Underground Spaces

In direct response to the "9.7" rainstorm, Shenzhen's Housing and Construction Bureau, the Water Authority of Shenzhen Municipality, and the Emergency Management Bureau jointly organised the drafting of the Technical Guideline for Urban Underground Space Flooding Prevention (SJG 162-2024), which was issued and took effect on 1 April 2024. It filled a national gap in dedicated technical standards for flooding prevention in urban underground spaces. Guided by the principle of

"prevention first, combining prevention, drainage and rescue", the guideline establishes a framework covering planning, construction, operation and maintenance, and emergency response. Its four main provisions are as follows:

First, differentiated protection standards are specified by facility category and risk level. All underground spaces must be designed to provide flood control corresponding to a return period of at least 100 years. Critical underground spaces—including underground commercial complexes with a total floor area exceeding 20,000 m², underground facilities of Grade-3A hospitals, metro facilities, and underground transport hubs—must have dedicated flood control designs, with site-specific flood control elevations determined through mathematical modelling.

Second, engineering measures for flood prevention are quantified. Pedestrian entrances must be elevated at least 0.45 m above the surrounding ground level and equipped with flood barriers 0.8 m above the ground. Vehicular ramps must incorporate a reverse-gradient section rising by no less than 0.15 m and flood barriers no less than 1.2 m in height. The design flood control elevation for sunken plazas must be at least 0.5 m above the inundation water level.

Third, mandatory constraints are imposed on the siting of equipment rooms. Transformer, power distribution rooms, and data centres in low-lying and flood-prone areas must not be located underground. In other areas, where a building has more than one basement level, transformer and power distribution rooms must be located on the first basement level or above. These requirements reduce the risk of secondary disasters caused by power-outage during flood events.

Fourth, monitoring, early warning and emergency management mechanisms are strengthened. Critical underground spaces must establish flood monitoring systems with real-time monitoring, data acquisition, risk alerting, and must be connected to Shenzhen's municipal data platform. All underground spaces must develop flooding emergency response plans specifying personnel evacuation routes and the evacuation preparation times.

(2) Advancing Coordinated River Basin Management across Administrative Boundaries

To address constraints on flood conveyance across administrative boundaries along the Shenzhen and Longgang rivers, the Water Authority of Shenzhen Municipality has made basin-wide flood control and drainage a key priority by strengthening spatial management for water infrastructure and prioritizing the allocation of space essential for flood control and drainage. The Aauthority is also promoting the incorporation of the downstream Huizhou section of the Longgang River into the regional flood control coordination framework to advance the harmonization of upstream and downstream management standards.

These efforts have made initial progress. In the Shenzhen section of the Longgang River, 210,000 m³ of sediment has been removed along 5 km, accounting for more than 95% of the project's total dredging volume and significantly improving flood conveyance capacity. Downstream, Huizhou has committed to upgrading flood control along the Huiyang section of the Danshui River to a 50-year return period standard. Improvements are being phased in, prioritizing bottlenecks, flood-prone reaches and downstream sections. The initial works of the Danshui River flood control and drainage project, with a total investment of RMB 480 million, were completed in 2025. The flow cross-sectional areas increased by an average of 13.5% in the urban flood control section and 22% in the Lenovo Industrial Park section. Institutionally, in April 2026, the Standing Committees of the Shenzhen and Huizhou Municipal People's Congresses conducted joint oversight of Danshui River basin management to promote alignment of upstream and downstream flood control standards. The Shenzhen Metropolitan Area Ecological and Environmental Protection Plan (2025–2030) also

includes management of transboundary rivers such as the Danshui River within the Shenzhen–Dongguan–Huizhou coordination framework.

(4) Establishing a Smart Management System for the Entire Process of Urban Flooding

In the post-disaster phase, the Water Authority of Shenzhen Municipality, the Emergency Management Bureau of Shenzhen Municipality and other relevant departments established the development of a dynamic updating mechanism for the Pluvial Flood Risk Map and streamlined the dissemination of forecasts and early warnings. They established risk-map-based flood scenario simulations and revised flood emergency response plans for different settings, including underground spaces, residential communities and metro systems, with clearly defined evacuation routes and response criteria. To support these measures digitally, data on water levels in flooded underground spaces, alarm signals and related parameters must feed into Shenzhen's municipal data platform. This digital platform supports a shared Pluvial Flood Risk Map and provides the data needed for coordinated responses across departments.

Implementation is gradually delivering results. For monitoring and early warning, the city has established 421 rainfall stations and 329 municipal hydrological monitoring stations, providing hydrological monitoring coverage for all rivers with catchment areas of 10 km² or more. River flood forecast lead time has increased from one hour to three hours. For risk management, the municipal office responsible for flood control, drought relief and typhoon prevention and the water affairs authority jointly issued the Shenzhen Flood Risk Atlas (2025 Edition). Working with meteorological authorities, the office also issued the Shenzhen Guidelines for Meteorological Disaster Risk Warnings (2025 Edition), with surface-water accumulation thresholds for each subdistrict updated dynamically. To clarify responsibilities, the city issued the Shenzhen List of Priority Tasks for Strengthening Disaster Prevention, Risk Reduction and Relief Capacity, comprising 74 tasks in 10 categories, and the Shenzhen Implementation Plan for Building a Safe and Resilient City. Pre-flood-season tasks were completed on schedule. During heavy rainfall associated with the 2024 "Dragon Boat rains" season and Typhoon Gaemi, flood barriers had been installed at all of the city's more than 5,000 underground spaces. The barriers performed effectively during these events, and the flood control measures played an important role.

III. Lessons Learned

(1) Technical Standards Are Essential to Systematically Strengthening Flood Control in Underground Spaces

Underground spaces in high-density megacities vary widely in type and function. Without unified, systematic and practicable flood control specifications, protection standards and engineering measures are inconsistent, creating vulnerabilities likely to be exposed simultaneously during extreme rainstorms. The first priority for high-density cities is therefore to strengthen dedicated technical standards. A coherent regulatory framework can systematically improve the overall flood control capacity of urban underground spaces and prevent systemic urban flood risks at the source.

(2) The Pluvial Flood Risk Map Should Serve as a Prerequisite for Urban Planning and Construction

City-wide risk assessment and a unified Pluvial Flood Risk Map, based on observed extreme rainfall data and hydrological modelling, together with risk management differentiated by level and category, are key tools for modernising urban flood governance. Urban planning and construction should make flood-risk assessment a prioritized consideration, making pluvial flood risk levels a mandatory basis for infrastructure siting, underground space development and retrofitting existing

facilities. Construction standards, remedial measures and management requirements should vary by risk zone. Precise risk identification and risk-based management can align the spatial distribution of disaster prevention measures with actual risks and shift flood governance from reactive emergency response to proactive risk prevention and management.

(3) Cross-Jurisdictional Coordination Mechanism Is the Key to Managing Flood Risk across River Basins

River basin flood management requires an integrated approach because conditions and interventions throughout a basin are interconnected. Inconsistent flood control standards and uncoordinated implementation between upstream and downstream areas and between opposite banks are common obstacles in rivers crossing municipal boundaries. A basin-wide approach and cross-jurisdictional coordination mechanisms for flood prevention and disaster risk reduction are therefore essential. Harmonizing core standards for river improvement, drainage capacity and flood control, removing cross-boundary bottlenecks in flood conveyance and discharge, and coordinating the siting and spatial management of water infrastructure can fundamentally improve flood resilience across the basin.