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Assessment of Urban Flood Risk and River Network Regulation Capacity Under Extreme Rainfall Conditions

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ABSTRACT

Global climate change has led to frequent extreme rainfall events, increasing the probability and intensity of urban flood disasters. This study employs a hydrological-hydrodynamic coupled method for urban flood risk assessment. The extreme "Zhengzhou 7·20" rainstorm event that occurred in China was transposed to Lianyungang City. An analysis of urban inundation and flood risk for 34 types of urban spatial objects across 3 categories was conducted, resulting in a compiled list of hidden hazards. With the objective of preventing overflow in main urban drainage channels while allowing overflow in most secondary channels, an analysis of the urban river network's regulation and storage capacity was performed. This study proposes the ultimate rainfall intensity bearing capacity of the urban engineering system, clarifies the distribution of urban flood risk hazards, and provides technical support for enhancing the city's ability to respond to extreme rainstorms.

KEYWORDS: Urban flood risk assessment; Extreme rainfall; Hydrological-Hydrodynamic coupled model; River storage capacity; Urban resilience

1 INTRODUCTION

Global climate change leads to frequent extreme rainfall events, increasing the probability and intensity of urban flood disasters (Rentschler et al.,1985; Zhang et al., 2016), while also highlighting the limitations of traditional flood disaster response models. Urban flood disasters caused by extreme rainstorms are often characterized by sudden onset, numerous hidden hazard points, significant impact, intertwined flood and waterlogging, multiple types of secondary disasters, and substantial losses. The catastrophic 2021 Zhengzhou "7·20" extreme rainstorm and the 2023 Zhuozhou "7·30" rainstorm in China resulted in significant casualties and property damage, providing painful lessons. Relevant management authorities can utilize the risk levels and distribution to implement early risk warnings, allocate resources, and organize evacuations in advance, thereby minimizing losses caused by flood disasters. Addressing the question posed by managers—"What magnitude of rainfall can the city's current flood control, drainage, and sewerage engineering system withstand?"—this study provides an answer by analyzing urban flood risk under different rainfall intensities and assessing the urban river network's regulation and storage capacity.

Existing risk assessments for extreme rainstorm flood disasters are mostly based on numerical simulation schemes. Domestic and international experts and scholars have conducted in-depth research on urban rainstorm and waterlogging risk assessment, which can be categorized according to their principles into hydrological methods, hydrodynamic methods, and hydrological-hydrodynamic coupled methods

(Huang et al., 2020;Xu et al., 2021;Qi et al., 2021). Hydrodynamic methods (including 1D hydrodynamic models, 2D hydrodynamic models, and 1D-2D coupled hydrodynamic models) offer significant advantages in the refined simulation of water flow dynamics. The hydrological-hydrodynamic coupled method combines the strengths of both hydrological and hydrodynamic approaches, yielding more accurate assessment results and broader applicability, and has been widely adopted in recent years. Commonly used rainstorm and flood models include SWMM (Storm Water Management Model), MIKE, InfoWorks ICM (Integrated Catchment Modelling), IFMS (Integrated (IWHR) Flood Modeling System), etc. (Li et al., 2022). Overall, the computational principles of these urban rainstorm and flood models are similar. However, due to the complexity of urban rainstorm and flood processes and data conditions, as well as insufficient understanding of model principles and simulation objects by modelers, significant discrepancies often exist between model construction aspects—such as delineation of the modeling area, runoff generation and concentration simulation, structure generalization, and engineering operation simulation—and actual conditions.

In light of this, this study takes the central urban area of Lianyungang City, where rainstorms and floods occur relatively frequently, as the research area. Based on an approach combining the physical mechanisms of surface drainage following the "surface ponding-pipe network-river network" concept with generalization methods, a refined model for the entire process of urban rainstorm and flood is constructed. This model is used to assess urban flood risk under extreme rainfall conditions and to analyze the urban river network's regulation and storage capacity, providing technical support for urban flood risk management under extreme conditions and for measures such as "prevention-evacuation-emergency response-rescue."

2 STUDY AREA

Lianyungang City is located in Jiangsu Province on the eastern coast of China, situated on the shores of the Yellow Sea, boasting a unique geographical location. Climatically, it belongs to the northern subtropical monsoon climate zone, characterized by four distinct seasons, mild temperatures, and humidity, but it also faces threats from summer typhoons and winter cold waves (Wang et al., 2024). The maximum annual precipitation was 1308.0 mm (2005), and the minimum was 504.9 mm (1978), with a ratio of maximum to minimum annual precipitation of 2.7. Spatial distribution of precipitation is also uneven, decreasing from south to north.

Figure 1: Distribution of water conservancy projects in Lianyungang city

3 RESEARCH METHODOLOGY

To systematically simulate the runoff generation, concentration, and inundation processes in Lianyungang's urban area under extreme rainfall conditions, this study employs InfoWorks ICM software to establish a hydrological-hydrodynamic coupled model. This model integrates watershed hydrological runoff generation, hydraulic transport in pipe networks and channels, and 2D surface inundation processes, enabling the reflection of interactions among watershed-pipe network-surface elements within a unified framework. The model encompasses 843 km of 1D river channels and pipe networks and 201,325 grid cells. Model validation was performed using measured water level data from a rainfall event on October 2, 2025. The average Nash-Sutcliffe Efficiency (NSE) was 0.93, indicating a good fit.

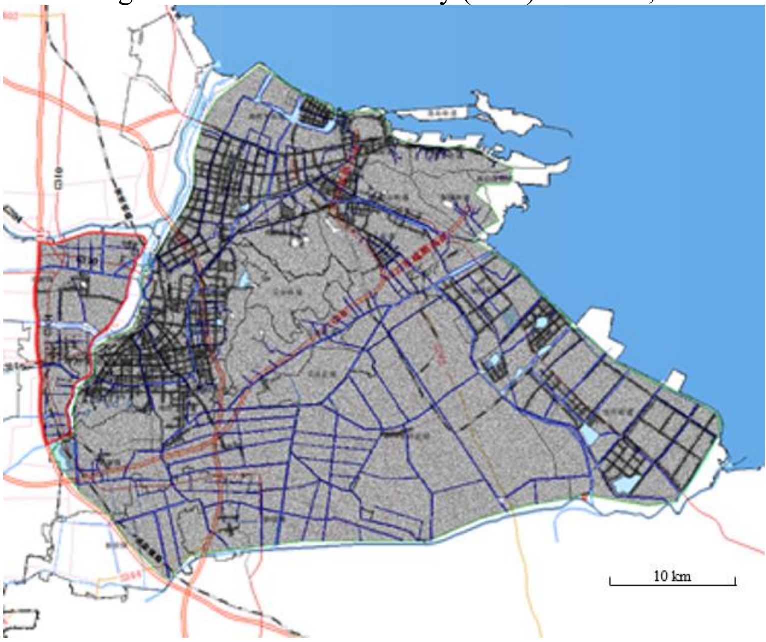

Figure 2: Model building

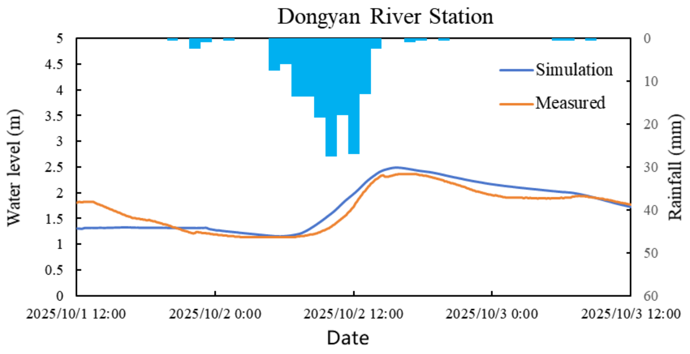

Figure 3: Modelling verification

4 ANALYSIS OF FLOOD RISK

Fully referencing the threat level of inundation depth to pedestrian safety and the mapping standards of the water resources industry, the inundation risk for extreme rainstorm events was divided into four levels: low risk (inundation depth 0.15m-0.3m), medium risk (inundation depth 0.3m-0.6m), high risk (inundation depth 0.6m-1.0m), and extremely high risk (inundation depth 1.0m and above). A flood risk map was generated based on the model calculation results. According to the risk map distribution, if the entire 1162.9 km² area of Lianyungang urban district were subjected to the Zhengzhou station rainstorm process (maximum 1-hour: 201.9 mm, maximum 24-hour: 645.6 mm, maximum 3-day: 789.1 mm), widespread flooding would occur. The total inundation area would be 526.23 km², accounting for 45.25% of the total area. The area with inundation depth exceeding 0.6 m would be 152.9 km², accounting for 29.06% of the total inundated area. The current engineering system would be unable to cope, making it crucial to prepare defense measures and emergency plans in advance. Compared to Lianyungang's current 20-year drainage standard (maximum 1-hour rainfall: 89.9 mm), the calculated 1-hour rainfall is 2.2 times higher; compared to the 20-year standard 24-hour rainfall (242.9 mm), the calculated 24-hour rainfall is 3.2 times higher. The proportions of different risk levels for each administrative district are shown in Table 1 and Table 2.

Based on fundamental data and model results, inundation risk maps were created. The flood disaster risk to urban spatial objects was analyzed, and thematic risk maps for these objects were produced. These involve 2 types of hydraulic structures (sluices, pumping stations), 7 types of lifeline projects (underground spaces, power supply facilities in low-lying areas, power supply facilities for underground spaces, water supply projects, underpass transportation works, transportation hubs, communication facilities, oil and gas stations), and 15 types of key protected objects (water-reactive hazardous chemical enterprises, highly toxic chemical enterprises, government service centers, hospitals, schools, nursing homes, welfare institutions, kindergartens, underground shopping malls, dilapidated buildings/houses/grain depots, geological hazard risk points, evacuation and resettlement sites/communities, and flood control material warehouses). A risk and hidden hazard checklist covering 24 types of key objects across 3 categories was compiled. The list includes risk elements such as the object's latitude/longitude, surrounding average ground elevation, ground water level during flooding, inundation depth, risk level, and risk point description. Based on this checklist, urban spatial objects at risk can be further identified.

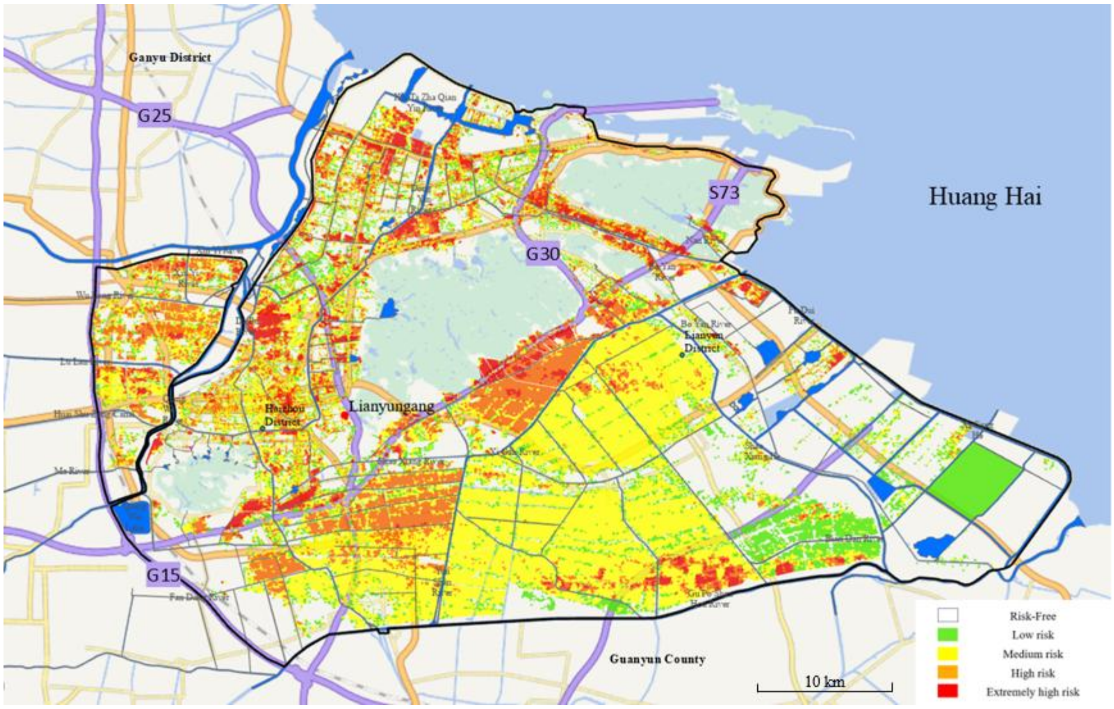

Figure 4: Urban Flood Risk Submersion Map under Extreme Heavy Rainfall Conditions

Table 1 Statistical table of submerged area and proportion of built-up area and non-built-up area in Haizhou District of Lianyungang City under the boundary scenario of '7·20' rainstorm combination in Zhengzhou

Risk level / Flooded area (km^2)	**Haizhou (243.59km^2)**							
	Haizhou (excluding Yuntai Mountain Scenic Area)				**Yuntai Mountain Scenic Area (0.06)**			
	built up area	**percentage**	**unbuilt area**	**percentage**	**built up area**	**percentage**	**unbuilt area**	**percentage**
Extremely high risk	8.31	2.88%	11.84	1.30%	/	/	/	/
High risk	12.58	4.36%	63.15	6.95%	/	/	0.02	0.00%
Medium risk	23.08	8.00%	93.48	10.28%	0.01	0.00%	/	/
Low risk	8.74	3.03%	22.35	2.46%	0.03	0.01%	/	/
Aggregate	52.70	18.28%	190.83	20.99%	0.04	0.01%	0.02	0.00%

Table 2 Statistical table of submerged area and proportion of built-up area and non-built-up area in lianyun district, lianyungang city, zhengzhou '7·20' heavy rain combination live boundary scenario

Risk level / Flooded area (km^2)	**Lianyun (282.64)**															
	Lianyun (excluding the development zone and Xuxu New Area) (31.91)				**Economic and technological development zone (56.17)**				**Yuntai Mountain Scenic Area (0.04)**				**Xuwei New District (194.52)**			
	built up area	**percentage**	**unbuilt area**	**percentage**	**built up area**	**percentage**	**unbuilt area**	**percentage**	**built up area**	**percentage**	**unbuilt area**	**percentage**	**built up area**	**percentage**	**unbuilt area**	**percentage**
Extremely high risk	2.90	1.01%	4.17	0.46%	8.12	2.82%	1.85	0.20%	/	/	0.01	0.00%	0.39	0.13%	3.97	0.44%
High risk	2.98	1.03%	5.98	0.66%	12.21	4.23%	2.46	0.27%	/	/	/	/	0.62	0.22%	11.35	1.25%
Medium risk	3.04	1.05%	7.40	0.81%	15.85	5.50%	2.18	0.24%	/	/	0.01	0.00%	0.97	0.34%	123.58	13.60%
Low risk	1.75	0.61%	3.70	0.41%	12.53	4.35%	1.00	0.11%	/	/	/	/	14.19	4.92%	39.44	4.34%
Aggregate	10.66	3.70%	21.25	2.34%	48.71	16.89%	7.48	0.82%	/	/	0.02	0.00%	16.17	5.61%	178.34	19.62%

5 RIVER NETWORK REGULATION AND STORAGE CAPACITY

River network regulation and storage capacity refers to the ability of a region's river channel system to temporarily store (regulate) and safely discharge (store + drain) rainwater during a rainstorm. The stronger this capacity, the greater the ability to resist flooding and prevent waterlogging.

This study evaluates the overflow risk of main channels and secondary drainage channels in key urban areas of Lianyungang City under designed 24-hour rainfall amounts of 300 mm, 350 mm, 400 mm, 500 mm, and 800 mm. The results are shown in the table below.

The results indicate that Lianyungang's urban river network regulation and storage capacity exhibits four main characteristics. First, the drainage method significantly impacts the capacity. For example, in the West Tongyu River area and the secondary channels of the Dapu River area, gate-controlled drainage generally enhances the channel's anti-overflow capability compared to pump-controlled drainage. This is because drainage capacity is a key component of the overall bearing capacity. Gate-controlled drainage allows for utilizing tidal conditions or low external river water levels for natural discharge, dynamically enhancing the river network's drainage capacity and thus increasing the overall bearing capacity. Pump-controlled drainage is limited by fixed power and becomes a bottleneck during extreme rainstorms. This highlights the importance of optimized operation for unlocking potential capacity.

Second, secondary channels are more prone to overflow than main channels. The main channels in the Dapu River area (Dapu River and Dongyan River) did not overflow under both pump and gate drainage scenarios for 24-hour rainfalls of 300 mm, 350 mm, 400 mm, and 500 mm. However, under pump drainage, secondary channels basically all overflowed even under the 24-hour 300 mm rainstorm. This indicates weaknesses exist within the river network system. Even if main channel capacity is strong, insufficient capacity or poor drainage in secondary channels can lead to local overflows, constraining the effective bearing capacity of the entire area.

Third, the Shaoxiang River overflowed in all scenarios. This area's river network has an inherently insufficient base regulation and storage capacity. The main reasons are its location at the southern foothills of Yuntaishan Mountain and the coastal plain, with higher terrain in the west and lower in the east. Upstream mountain floods and regional stormwater converge rapidly, while the downstream terrain is flat. The estuary is affected by tides, and drainage is hindered during high tide, leading to limited outlet capacity. Even with gates open (gate drainage), water levels cannot be effectively lowered.

Furthermore, extreme rainfall (800 mm) poses severe challenges to all areas, with water levels in most channels approaching or exceeding safety limits. This indicates an upper limit to the current river network system's bearing capacity. Almost all areas were near or beyond their limits under the 800 mm scenario. Therefore, facing super-standard rainstorms requires reliance on emergency management or stronger engineering measures.

Considering the above issues, several governance approaches are proposed. First, for areas with weak regulation and storage capacity like the Shaoxiang River area, it is necessary to expand storage volume (through dredging, channel widening) or construct powerful pumping stations. For areas like the West Tongyu River area, priority should be given to optimizing drainage operations and considering upgrading pumping station capacity. For secondary channel bottlenecks, it is essential to improve the pipe network and enhance channel connectivity and flow capacity. Emergency management measures need to be formulated for different areas when rainfall exceeds the river network's regulation and storage capacity.

Table 3 Elevation of main waterways in each drainage zone and water levels under different heavy rainfall scenarios (yellow shading indicates water levels exceeding ground elevation, bold lines represent major waterways)

Drainage area	**River name**	**Ground elevation (m)**	**Water level (m)**									
			300 mm in 24 h		**350mm in 24 h**		**400mm in 24 h**		**500mm in 24 h**		**800mm in 24 h**	
			pump	**Sluice**	**pump**	**Sluice**	**pump**	**Sluice**	**pump**	**Sluice**	**pump**	**Sluice**
Dapu River area	Dapu River	4.58	4.14	2.71	4.15	2.90	4.16	3.07	4.44	3.36	4.82	4.08
	Dongyan River	4.80	4.17	3.71	4.21	3.89	4.31	4.06	4.51	4.32	4.88	4.77
	Longwei River	3.83	4.17	3.58	4.20	3.78	4.30	3.98	4.49	4.27	4.83	4.69
	Yudai River	4.23	4.18	3.75	4.29	3.95	4.36	4.12	4.63	4.46	5.15	5.12
	Dapufu River	3.97	4.14	3.17	4.23	3.59	4.24	3.76	4.39	4.05	4.71	4.51
West Tongyu River area	Yan River	4.03	4.10	3.40	4.20	3.88	4.25	4.03	4.41	4.26	4.72	4.65
	Bayi River	4.23	4.06	3.11	4.19	3.49	4.28	3.62	4.40	3.90	4.66	4.51
Shaoxiang River area	Shaoxiang River	3.23	3.51	3.71	3.55	3.43	3.59	3.49	3.67	3.57	3.90	3.81
	Yunshan River	3.73	3.52	3.34	3.57	3.37	3.61	3.43	3.68	3.57	3.94	3.81
	Shaoxiangnan River	3.63	3.53	3.10	3.58	3.42	3.62	3.49	3.69	3.59	3.86	3.80
Lingang area	Caowei River	4.23	3.51	3.36	3.57	3.42	3.93	3.87	4.16	4.03	4.35	4.33
Paidan River area	Paidan River	4.29	3.74	3.28	3.84	3.67	3.94	3.80	4.13	4.04	4.56	4.52
	Beipaidan River	4.23	3.90	3.32	4.03	3.37	4.17	3.46	4.34	3.61	4.66	3.95
Xuwei area	Xuwei River	4.03	2.81	2.05	2.80	2.38	2.80	2.48	2.93	2.71	3.71	3.44

6 CONCLUSION

This study focused on Lianyungang City as the research area, collecting data on urban hydrology, river networks, hydraulic engineering, stormwater and municipal drainage networks, and high-resolution terrain. A refined, hydrological-hydrodynamic coupled model for the entire urban rainstorm and flood process was constructed and calibrated/validated using historical typical rainstorms. A flood risk simulation was conducted by transposing the "Zhengzhou 7·20" rainstorm to Lianyungang. The simulation indicates that Lianyungang's current flood control and drainage system would be unable to cope with a "Zhengzhou 7·20" type rainstorm, making advance preparation of defense measures and emergency plans crucial. Regarding the adjustable storage capacity of the urban river network, under pump drainage conditions, the existing main channels (except Shaoxiang River) can generally regulate and store rainfall up to 400 mm in 24 hours, during which most secondary channels would overflow. Under gate drainage conditions, the existing main channels (except Shaoxiang River) can generally regulate and store rainfall up to 500 mm in 24 hours, during which most secondary drainage channels would overflow.

In the research on urban resilience for coping with flood disasters, there is an urgent need to establish urban resilience assessment methods suitable for responding to extreme rainstorm and flood disasters. Based on evaluation results, vulnerable links in flood disaster prevention and control can be identified, providing technical support for enhancing urban resilience.

7 ACKNOWLEDGEMENTS

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REFERENCES

Rentschler J., Avner P, Marconcini M., et al. (1985). Global evidence of rapid urban growth in flood zones since. Nature, 2023, 622(7981): 87-92.

Zhang J., Wang Y., He R., et al. (2016). Discussion on the urban flood and waterlogging and causes analysis in China. Advances in Water Science, 27(4): 485-491. (in Chinese))

Huang G.,Luo H.,Lu X,,et al. (2020) Study on risk analysis and zoning method of urban flood disaster. Water Resources Protection, 36: 1-6,17.(in Chinese))

Xu Z., Ye C. (2021).Simulation of urban flooding/waterlogging processes: Principle, models and prospects. SHUILI XUEBAO, 52: 381-92.(in Chinese))

Qi W., Ma C., Xu H., et al. (2021). A review on applications of urban flood models in flood mitigation strategies . Natural Hazards, 108(1): 31-62.

Li C., Sun N., Lu Y., et al. (2022). Review on urban flood risk assessment. Sustainability, 15(1): 765.

Wang D., Ji C., Zhang L., et al. (2024). Multi-methods combination assessment and application of urban flood risk. Science of Disaster， 39(1): 96-103.