Analysis of the Correlation between Urban Waterlogging and Precipitation in Tongliao City

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Abstract Tongliao City is located in the alluvial plain of the West Liao River, where short-duration heavy precipitation occurs frequently in summer, and urban waterlogging has become the main meteorological disaster affecting the safe and sustainable development of the city. Based on the geographical location, topography and climate characteristics of Tongliao City, the causes of urban waterlogging were analyzed from natural factors, urban development, infrastructure and management systems. According to local infrastructure construction, the risk of urban waterlogging was classified based on waterlogging characteristics, and the distribution characteristics of urban waterlogging and its response relationship with hourly rainfall intensity were discussed. The results show that urban waterlogging was strongly correlated with short-duration heavy precipitation in Tongliao City, which can provide a reference for the monitoring and early warning of urban waterlogging as well as flood control and drainage management.

Key words Urban waterlogging; Waterlogging level; Waterlogging depth; Correlation; Tongliao City

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In recent years, extreme precipitation events have been increasing in northern Chinese cities, and the urbanization process has accelerated. As a result, problems such as impervious underlying surfaces and insufficient drainage capacity have become increasingly prominent, leading to frequent and severe urban waterlogging. Tongliao City, as an important transportation hub connecting the northeastern and northern regions of China, is located in the middle and lower reaches of the Xiliao River. The terrain is gentle, and the drainage conditions are relatively poor. In summer, cold vortex weather happens frequently, which can easily trigger local rainstorms and short-duration heavy precipitation, thereby easily causing waterlogging in urban areas, and resulting in traffic disruptions, water ingress in underground spaces, and damage to municipal facilities.

Precipitation is the decisive meteorological factor for the formation of urban waterlogging. The intensity, duration, and spatial and temporal distribution of precipitation directly control the entire process of the occurrence, development, and recession of urban waterlogging. Currently, there are relatively few systematic studies on the relationship between urban waterlogging and precipitation in Tongliao City, and there is a lack of waterlogging threshold and grade classification standards based on local precipitation characteristics. Therefore, the analysis of the correlation between urban waterlogging and precipitation in Tongliao City is of great practical significance for enhancing the accuracy of flood warnings and improving the drainage and flood prevention system.

1 General situation of Tongliao City

1.1 Geographical location Tongliao City (42°15′ - 45°41′ N, 119°15′ - 123°43′ E) is located in the east of Inner Mongolia Autonomous Region, at the western end of the Songliao Plain, and in the hinterland of the Horqin Grassland. Its geographical coordinates range from 42°15′ N to 45°41′ N, and from 119°15′ E to 123°43′ E. The city borders Jilin Province to the east, Liaoning Province to the south, Chifeng City and Xilingol League to the west, and Xing'an League to the north. It is approximately 418 km long from north to south and 370 km wide from east to west, with a total land area of 59 535 km^2.

1.2 Topography and landform There are deserts, grasslands, wetlands, lakes, sparse forests, and mountains within Tongliao City. It belongs to the typical Horqin sparse forest and grassland topography. In terms of terrain, it is high in the south and north and low in the middle, showing a saddle-shaped pattern. There are rocky mountains and hills formed by the southern foothills of the Greater Khingan Range in the north, with an altitude of 400 - 1 444 m; there is the sandy alluvial plain of the Xiliao River Basin in the middle, with an altitude of 120 - 320 m, which is the main topography of the city; there are shallow mountains and loess hills at the edge of the Liaoxi Mountains in the south, with an altitude ranging from 550 to 730 m. In the transitional zone between alluvial plain, mountains and hills, sand dunes and sandy areas are widely distributed, with an altitude mostly ranging from 200 to 400 m.

1.3 Climate characteristics Tongliao City is situated in the eastern part of the Eurasian continent, and has an arid to semi-arid climate. The climate is weakly regulated by the ocean. The four seasons are distinct under the alternating influence of the Siberian - Mongolian cold high-pressure system and the southeast monsoon.

Horqin District, as the main urban area of Tongliao City, has a mid-temperate semi-arid continental monsoon climate. The annual average temperature is 7.5 ℃, and the annual average pre-

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cipitation is 382 mm (data compiled over 30 years from 1997 to 2020). In spring, temperature rises rapidly, and windy weather occurs frequently; droughts happen frequently. In summer, precipitation is concentrated, and rain and heat coincide, so it is prone to periodic waterlogging. In autumn, it is short and cool, with a rapid drop in temperature, and frost occurs earlier in the north and later in the south. Winter is long, cold and dry.

2 Causes of urban waterlogging

At present, numerous scholars both at home and abroad have conducted extensive research on the causes of urban waterlogging. Current studies show that the formation of urban waterlogging is mainly attributed to natural factors, urban development and construction, inadequate infrastructure, and incomplete management system[1-2].

2.1 Natural factors Natural factors play a significant role in the formation of urban waterlogging. Since 1850, global average temperature has risen by approximately 1 ℃. The increase in temperature has increased the saturated water vapor content in the atmosphere, accelerated the hydrological cycle process, and reduced its stability, which is prone to triggering intense concentrated precipitation. The large amount of runoff generated by short-duration heavy rainfall exceeds the infiltration capacity of the surface, and the rapid accumulation of runoff is likely to cause waterlogging in low-lying areas. At the same time, regional topography and terrain characteristics determine the convergence path and accumulation areas of runoff. Flat and low-lying urban areas have poorer drainage capacity and flood control, and it is prone to water retention, which significantly increases the risk of waterlogging[3].

2.2 Urban development With the rapid advancement of urbanization, there are issues such as unreasonable layout, excessive development intensity, and high proportion of hard surfaces on the ground during urban planning and construction. The impermeable paved surfaces such as roads, squares and buildings within the city area continue to expand, while the area of soil, green spaces, and water bodies that originally had natural infiltration and water storage capabilities has decreased year by year. As a result, the degree of pavement hardening in cities is constantly increasing, and the permeability is significantly decreasing; the surface runoff coefficient and runoff volume continue to rise, so that rainwater is easy to accumulate in urban low-lying areas, thereby triggering urban waterlogging[4].

2.3 Inadequate infrastructure At present, the central urban area of Tongliao City has entered a rapid urbanization process. During the initial stage of urban planning, the terrain and landform characteristics of the Xiliao River basin, the conditions of arid and semi-arid continental monsoon climate, and the development factors of the central urban area were not fully considered, resulting in a disconnection between the urban drainage system and the development needs of the city, as well as poor coordination among rainwater collection, transportation, and discharge. Among them, the drainage pipelines in the old urban area of Horqin were mostly constructed in the 1990s and earlier, and generally had low construction standards and scattered layout of pipelines. With the continuous concentration of urban population and the continuous expansion of the built-up area, the insufficient drainage capacity of the pipelines and the low drainage efficiency have become increasingly prominent. The risk of waterlogging at nodes such as Mingren Overpass, Wulanhua Road, and Xingong First Road Overpass is particularly high. In addition, during the development of new areas and the renovation of old urban areas, there is a lack of precise connection and integration of new and old drainage pipelines, which easily forms drainage capacity bottlenecks and significantly weakens the overall efficiency of drainage and flood prevention[5].

2.4 Incomplete management system The prevention, control and management of urban waterlogging is an effective means to deal with urban waterlogging disasters and is also an important supplement to engineering measures for waterlogging prevention. According to statistics, the central urban area of Tongliao City experienced 5 waterlogging disasters from 2022 to 2025. Among them, the frequency was 1 in each year from 2022 to 2024 and 2 in 2025. In the two heavy rainfall processes in June and July in 2025, the rainfall significantly exceeded the existing design standard of waterlogging prevention, thereby causing widespread waterlogging and traffic disruptions, *etc.*, and further exposing the shortcomings of urban flood control and drainage management system. Currently, Tongliao City has initially established a comprehensive, systematic, and integrated prevention and control management mechanism, but there are still deficiencies in departmental coordination and collaboration, daily operation, maintenance and management, risk hazard rectification, and emergency dispatch and handling.

3 Classification of urban waterlogging

Urban waterlogging directly leads to problems such as flooded roads and traffic paralysis. In severe cases, it not only causes property damage but also poses a direct threat to residents' personal safety. Meanwhile, waterlogging is prone to breeding harmful bacteria, causing water pollution, and triggering public health hazards.

Waterlogging depth is the core indicator of the severity of urban waterlogging. To clarify the impact of waterlogging depth on urban waterlogging, many scholars have conducted research on the impact of urban waterlogging in various scenarios such as traffic roads, commercial-residential and residential areas, underground garages, and urban infrastructure, and classified the risk levels of urban waterlogging based on waterlogging depth[6-8]. According to the current situation of natural geography and urban construction in Tongliao City, the impact of waterlogging depth on the production and life of local resident as well as social operation was analyzed. The risk of urban waterlogging can be classified into four levels: mild risk, low risk, medium risk, and high risk. The specific classification criteria are shown in Table 1.

Table 1 Classification of urban waterlogging

Risk	Waterlogging depth // cm	Impact
Mild risk	≤4.9	It has a certain impact on vehicle traffic and residents' lives and almost no effect on the number of vehicles in garages. It is unlikely to cause property damage.
Low risk	5 – 19.9	It affects residents' normal lives and vehicle traffic, and causes traffic congestion. It may have an impact on vehicles with low exhaust pipes, and there is a high possibility of causing property damage.
Medium risk	20 – 49.9	It may cause traffic blockage, affect residents' lives, and cause engine damage and water ingress into the vehicle body for vehicles with lower exhaust pipes and a lower chassis, resulting in property damage.
High risk	≥50	It causes damage to vehicle engines, water infiltration into the compartment, inability of vehicles to move, and traffic paralysis, severely affecting the lives of residents and causing considerable property losses.

4 Analysis of the correlation between urban waterlogging and precipitation

Based on the actual monitoring data of hourly rainfall and waterlogging depth on each road in the main urban area of Tongliao City from 2024 to 2025, the intrinsic correlation between urban waterlogging and rainfall in Tongliao City was analyzed from the distribution characteristics of urban waterlogging, the correlation between urban waterlogging and hourly rainfall intensity, and the relationship between urban waterlogging and climate change, providing scientific support and practical references for the prevention and control of urban waterlogging.

4.1 Distribution characteristics of urban waterlogging From 2024 to 2025, a total of 66 waterlogging locations were monitored in the main urban area of Tongliao City. According to the classification standards for urban waterlogging, there were 13 low-risk locations, accounting for 19.7% of the total locations; the number of medium-risk locations was 50, accounting for 75.8%; the quantity of high-risk locations was 3, accounting for 4.5% (Fig. 1). It can be seen that the risk of urban waterlogging in concentrated rainfall periods in Tongliao City was mostly medium, followed by low risk, and the frequency of high risk was relatively low.

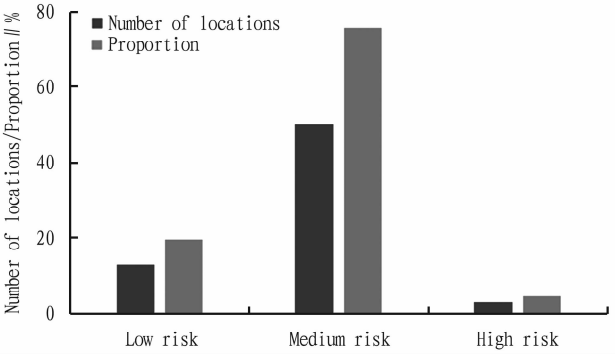

Fig. 1 Distribution characteristics of urban waterlogging

4.2 Correlation between urban waterlogging and hourly rainfall intensity The formation of urban waterlogging is not only driven by human factors such as urban development but also closely related to precipitation conditions. The correlation between waterlogging depth and hourly rainfall in the main urban area of Horqin during the concentrated rainfall periods from 2024 to 2025 was analyzed. As shown in Fig. 2, average waterlogging depth has a moderate positive correlation with the maximum hourly rainfall intensity within the study area, with a correlation coefficient of 0.653 2, indicating a significant positive correlation between the two. Hourly rainfall intensity can directly reflect the spatial and temporal concentration degree of precipitation. Short-duration heavy rainfall can easily cause the urban drainage system to be overloaded in a short period of time, and significantly reduce the efficiency of rainwater drainage, thereby triggering urban waterlogging.

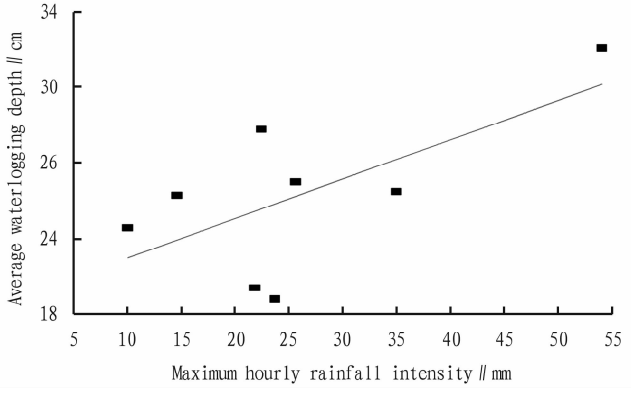

Fig. 2 Correlation between waterlogging depth and hourly rainfall intensity

4.3 Correlation between urban waterlogging and climate change In recent years, extreme precipitation events, especially short-duration and long-duration heavy precipitation, have occurred frequently and intensively. The observational data of precipitation from the Tongliao national meteorological observation station from 1981 to 2025 show that before 2004, there were no short-duration heavy precipitation events with hourly precipitation and 3-hour precipitation ≥ 20 mm. From 2005 to 2025, such events began to occur, and showed an increasing trend year by year; the number of effective precipitation days throughout the year also tended to rise. These changes indicate that the increase in short-duration heavy precipitation caused the overloading of urban drainage systems, thereby exacerbating the risk of urban waterlogging.

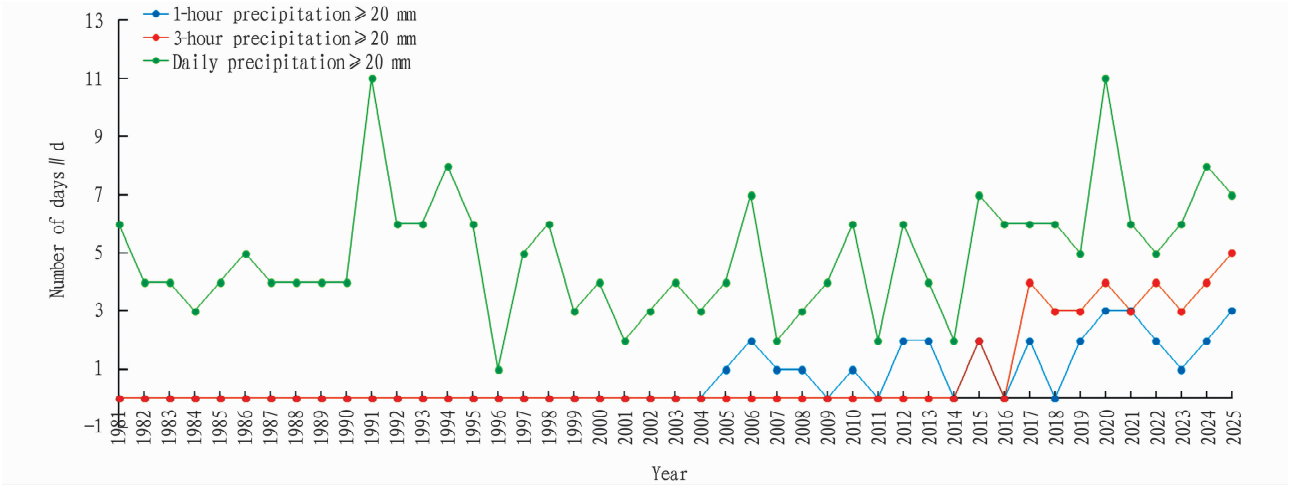

Fig. 3 Number of days with 1-hour precipitation, 3-hour precipitation and daily precipitation ⩾ 20 mm in Tongliao City from 1981 to 2025

5 Countermeasures against urban waterlogging

5.1 Establishing a complete whole-process waterlogging prevention system Tongliao City is located in the alluvial plain of the West Liao River. The terrain is flat, and the large rainfall runoff and rapid runoff are the main causes of urban waterlogging. An integrated prevention system of "source control – process management – end treatment" can be established. Meanwhile, it is needed to promote green roofs, renovate permeable paving, and increase green coverage to enhance the retention capacity of rainwater and slow down runoff rate. At the same time, relying on the connection of water systems and the ecological restoration project in Horqin, the storage and purification capacity should be enhanced to strengthen the city's resilience of waterlogging resistance.

5.2 Strengthening the scientificity and forward-looking nature of urban planning Urban planning is the core driving force for urban development. Scientific planning and design are essential for preventing urban waterlogging. During the stage of urban planning, it is necessary to conduct comprehensive on-site investigations, use physical models to simulate and analyze the formation mechanism and evolution pattern of urban waterlogging, verify and optimize the rationality and feasibility of waterlogging prevention measures, and enhance the overall waterlogging resistance capacity of the city at the planning level.

5.3 Improving the departmental collaboration mechanism to achieve comprehensive public governance The emergency management, housing and urban planning, and meteorology departments need to establish a collaborative and coordinated mechanism, strengthen regular consultation and analysis, set warning indicators of urban waterlogging, promptly and accurately issue warning information, and efficiently activate emergency responses. Meanwhile, they carry out preliminary handling work such as clearing and dredging of drainage networks, reinforcement of low-lying sections, control of underpass tunnels and underground spaces in advance. Besides, it is needed to guide the public to participate in the investigation of waterlogging hazards, actively reduce human-induced waterlogging, and jointly safeguard the lives and property safety of the people, and build a solid and reliable urban safety defense line.

References

[1] LI L, LI L, ZHAI ZB, *et al.* Causes and countermeasures of urban waterlogging in plain and hilly areas[J]. Northwest Hydropower, 2024(3): 9 – 14.

[2] MU JC, TAO Y. Study on the cause and control countermeasures of urban waterlogging in Suining, Sichuan[J]. Urbanism and Architecture, 2022, 19(4): 50 – 52, 132.

[3] ZHAO CH, WAN JH, ZHANG YX, *et al.* Review of the characteristics, causes and governance of urban flood in China[J]. Journal of Catastrophology, 2023, 38(1): 220 – 228.

[4] LIU XH. Analysis of causes of urban waterlogging and research on intelligent flood control strategies[J]. Urban Construction Theory Research (Electronic Edition), 2024(35): 208 – 210.

[5] LI SY. Analysis of causes of urban waterlogging and study on countermeasures for its control[J]. City and Town Water Supply, 2023(5): 93 – 96.

[6] GAO WY, LI M, LI J. Distribution characteristics of urban waterlogging and its relationship with rainfall in Xi'an[J]. Journal of Shaanxi Meteorology, 2014(2): 17 – 20.

[7] ZHOU LN. Research on the identification of urban waterlogging risk based on SWMM[D]. Sichuan: Southwest Jiaotong University, 2016.

[8] ZHANG ZT, CHEN J, REN H. Research on urban waterlogging prediction indicators in the old urban area of Jining[J]. Meteorology Journal of Inner Mongolia, 2025(3): 43 – 47, 61.