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Strategies for Urban Roadway Traffic in Response to Extreme Rainfall: A Case Study of the July 20, 2021 Torrential Rainstorm in Zhengzhou

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Abstract: Urban roads play a critical role in emergency rescue, and effectively reducing the risks posed by extreme rainfall is crucial to building resilient cities. By comprehensively considering factors such as rainfall volume, road waterlogging depth, and maximum allowable drainage time, this paper presents the development of boundary conditions for extreme rainfall events. Based on the analysis of road damage and traffic operation during the July 20, 2021 torrential rainstorm in Zhengzhou, the paper identifies high-risk road zones under extreme rainfall conditions. It highlights that areas, where traditional flat low-lying areas overlap with elevated roadbeds, urban waterlogging-prone zones, coincide with traffic congestion, and ramp exits on elevated expressways are particularly vulnerable during extreme weather events. Moreover, emergency response strategies for urban roadway traffic during extreme rainfall are proposed, including constructing a major emergency access route network, improving emergency evacuation plans, and refining the design of road drainage channels. Finally, the paper emphasizes that under extreme weather conditions such as excessive rainfall, cities need top-level planning, refined design, and emergency management of urban roads to enhance the overall disaster response capacity. **DOI:** 10.13813/j.cn11-5141/u.2024.0506-en

Keywords: emergency traffic; extreme rainfall; high-risk road zones; emergency channel network; emergency evacuation; drainage channels; Zhengzhou

0 Introduction

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) reveals that the intensity of extreme daily rainfall events will increase by 7% [1] with every 1 ℃ increase in global warming in the future. The July 20, 2021 torrential rainstorm in Zhengzhou, as a typical extreme rainfall event, has caused a severe waterlogging disaster, resulting in 380 deaths or missing persons as well as direct economic losses of CNY 40.9 billion [2].

As the lifeline project in cities, urban road traffic plays a crucial role in emergency rescue. However, due to its exposure to disasters as an open facility, it is more susceptible to waterlogging, especially at special sections such as ramp exits on urban elevated expressways and tunnels. Therefore, it is critically important to conduct research on strategies for urban road traffic management in response to excessive rainfall events to safeguard urban life safety.

Existing studies in China on urban road traffic under waterlogging scenarios predominantly focus on the impact of rainfalls within the standard of urban waterlogging prevention, with limited attention to road traffic response strategies for rainfalls exceeding this standard. Chen et al. [3] quantitatively analyzed the effects of varying degrees of rainfalls on the urban transport system and subsequently proposed specific early warning countermeasures. Fan [4] developed a comprehensive evaluation index system and a two-tier evaluation model based on road network vulnerability theory to assess vulnerability and identify critical areas of waterlogging in a specific district of Shenzhen City. Fang [5] conducted a preliminary discussion on the current status of urban rainwater drainage facilities in China, risk standards for urban ponding and waterlogging, as well as preventive and emergency measures for excessive rainfalls. However, this research remains relatively broad and lacks detailed, targeted response measures for urban road traffic.

During the torrential rainstorm that struck Zhengzhou on July 20, 2021, tunnels and bridges within the main urban area were largely disrupted due to the disaster. The waterlogging depth on some roads exceeded 150 cm, leading to temporary paralysis of urban traffic and posing significant challenges to disaster relief and post-disaster reconstruction efforts. By analyzing the damage to road facilities and traffic conditions during this event, this paper categorizes road risk areas under excessive rainfall scenarios, examines the specific situations in these risk areas, and proposes targeted response strategies for urban road traffic.

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1 Boundary conditions for excessive rainfall events

Excessive rainfall is defined as heavy precipitation that surpasses the established urban waterlogging prevention standards. According to the Emergency Response Plan for Extreme Rainfall Disasters in Wuhan [6], extreme rainfall is specifically characterized as precipitation exceeding 100 mm within one hour or more than 300 mm over a continuous 24-hour period.

Due to variations in urban types, the construction conditions of drainage and waterlogging prevention facilities, the degree of ponding impact, and waterlogging prevention standards, relying solely on rainfall intensity to determine the boundary conditions for traffic risks associated with extreme rainfall does not accurately reflect reality. This paper comprehensively considers factors such as rainfall intensity, road waterlogging depth, and maximum allowable drainage time to investigate the boundary conditions for traffic risks associated with extreme rainfall.

Taking Zhengzhou as a case study, according to the Comprehensive Planning for Drainage (Rainwater) and Waterlogging Prevention in Zhengzhou (2021–2035) [7], the design recurrence interval standard for urban waterlogging prevention and control in the central urban area of Zhengzhou (including the main urban area and the Airport Economy Zone) specifies that the urban area should be capable of withstanding a once-in-a-century 24-hour rainfall event (253.5 mm). Specifically, this standard requires that the ground floors of residential and commercial buildings should remain dry, the waterlogging depth in one lane of the road should not exceed 15 cm, and the maximum allowable drainage time in the central urban area should not exceed 2 hours (see Table 1 and Table 2).

Surface gathered water has a significant impact on urban road traffic. When the waterlogging depth exceeds the height of the road curb, it becomes difficult for pedestrians and drivers to distinguish between motorized and non-motorized lanes, posing hazards to traffic safety. When the waterlogging depth surpasses the height of a motor vehicle's exhaust pipe, water entering the exhaust system can damage the engine, leading to vehicle malfunction and immobilization, thereby causing paralysis of urban road traffic and necessitating road closure and control measures. Regarding the threshold value for waterlogging depth, S. M. H. Shah et al. [8] have developed safety guidelines for maintaining vehicle stability on waterlogged roads, while Huang et al. [9] proposed that when the waterlogging depth reaches 30 cm, which is approximately the height of a car's exhaust outlet, this can serve as a criterion for initiating road closures.

Considering the factors mentioned above, the boundary conditions for traffic risks associated with extreme rainfall events are defined as follows: 24-hour rainfall exceeding the urban maximum waterlogging prevention standard, road waterlogging depth surpassing 30 cm, and water accumulation duration exceeding 2 hours.

2 Analysis of road risk areas

Urban road risk areas are analyzed by taking the July 20, 2021 torrential rainstorm in Zhengzhou as an example.

2.1 Case profile of extreme rainfall

From 18:00 on July 18 to 0:00 on July 21, 2021, Zhengzhou City experienced an unprecedented continuous heavy rainfall event, with widespread torrential and extremely heavy rainfall across the city. The cumulative average rainfall reached 449 mm, and the maximum daily rainfall of 624.1 mm occurred on July 20. This amount was nearly equivalent to the city's average annual rainfall of 640.8 mm and represented 3.4 times the historical maximum daily rainfall (189.4 mm) recorded since the establishment of the Zhengzhou National Basic Meteorological Station in July 1978 [2].

Table 1 Design recurrence interval requirements for urban waterlogging prevention and control

Area	Recurrence interval of urban waterlogging prevention and control/a	Design standard for surface gathered water
Main urban area and Airport Economy Zone	100	The ground floors of residential buildings and commercial structures should remain dry; the waterlogging depth in one lane of the road does not exceed 15 cm
Suburban clusters of Zhongmou, Xingyang to Shangjie, South Dragon Lake, and Xinzheng	50	
Outskirt clusters of Gongyi, Dengfeng, and Xinmi	30	

Source: Reference [7].

Table 2 Maximum allowable drainage time under the design recurrence interval for urban waterlogging prevention and control

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Project	Area types			
	Central urban area	Non-central urban area	Important regions of the central urban area	Transport hub area
Maximum allowable drainage time	2.0	3.0	1.0	0.5

Notes: The central urban area refers to the clearly defined urban scope within each functional cluster and the maximum allowable drainage time represents the maximum allowable time for draining the surface gathered water after the rain ceases. Source: Reference [7].

Due to this torrential rainstorm, the area in Zhengzhou with cumulative rainfall exceeding 400 mm reached 5,590 km^2, and that exceeding 600 mm reached 2,068 km^2. Specifically, the cumulative rainfall in Erqi District, Zhongyuan District, and Jinshui District approached 700 mm, while Gongyi City, Xingyang City, and Xinmi City surpassed 600 mm. Zhengdong New Area and Dengfeng City recorded cumulative rainfall approaching 500 mm. The maximum water depth on the main urban roads reached nearly 2.6 m [2] (see Fig. 1). By July 22, the waterlogging in the main urban area had gradually subsided. Based on indicators such as 24-hour rainfall, road waterlogging depth, and waterlogging duration, this event was classified as a typical extreme rainfall.

2.2 Disaster situation of road facilities

Zhengzhou City has a total of 2,146 urban roads, including 335 expressways and trunk roads, 419 secondary trunk roads, and 1,392 branch roads and neighborhood roads. The urban area contains 67 tunnels, which were largely disrupted by the heavy rainfall.

Based on the waterlogging depth, urban roads are classified into six levels (see Fig. 2). Given that Zhengzhou's overall terrain is higher in the southwest and lower in the northeast, areas with waterlogging depths exceeding 100 cm were predominantly distributed in the northwest and southeast regions. Some roads in the eastern part experienced waterlogging depths surpassing 150 cm. Tunnel pump stations and other facilities in the main urban areas were severely affected, particularly at critical locations such as the intersections of Beijing-Guangzhou Railway, Jingguang Road, and Zhongzhou Avenue, where waterlogging depths exceeded 150 cm.

2.3 Traffic conditions of roads

Based on statistical data from the Gaode Maps API platform, a post-disaster traffic condition analysis for the main urban area of Zhengzhou City was conducted as follows.

2.3.1 Initial stage of the disaster

On July 20, 2021, due to a severe torrential rainstorm, roads across the city were extensively flooded, leading to a significant reduction in vehicle speeds. The average travel speed in the main urban areas dropped to less than 20 km·h^{-1}, far below the pre-disaster level of 34.4 km·h^{-1} (see Fig. 3).

2.3.2 Middle stage of the disaster

On July 23, except a few still-disconnected traffic nodes, traffic on most roads in the main urban area resumed. However, due to the ongoing disaster impacts and flood relief efforts, daily travel volumes remained relatively low. In major roads such as Manhattan Road and Jingguang Road, the main urban areas could be mostly traversed within 30 minutes during morning peak hours (Fig. 4). The overall condition of the urban road network was relatively good. During evening peak hours, the average travel speed in the main urban area was approximately 31.3 km·h^{-1}, gradually returning to pre-disaster levels.

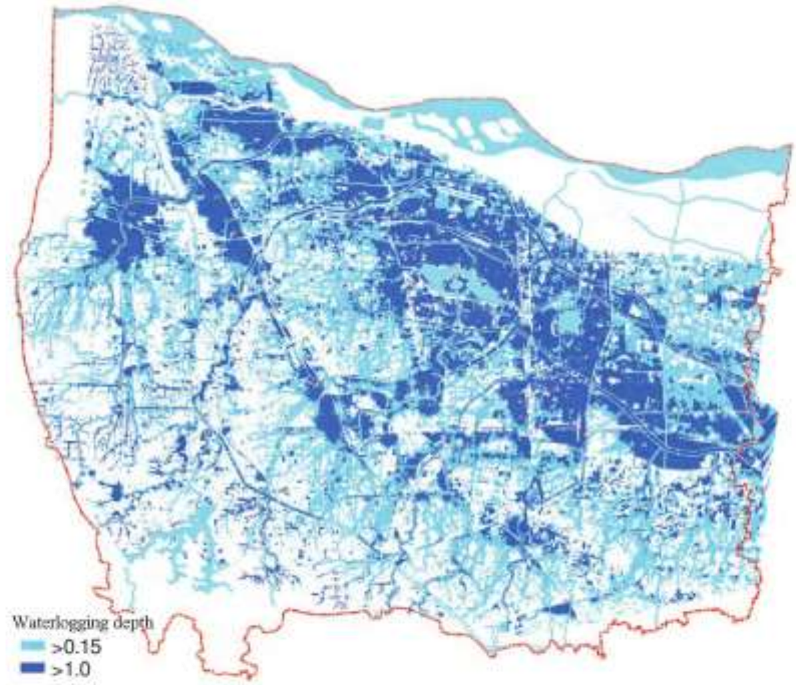

Fig. 1 Waterlogging distribution in Zhengzhou's main urban area during the July 20, 2021 torrential rainstorm

Source: Reference [7].

Fig. 2 Road waterlogging distribution in Zhengzhou's main urban area during the July 20, 2021 torrential rainstorm

Source: Reference [10].

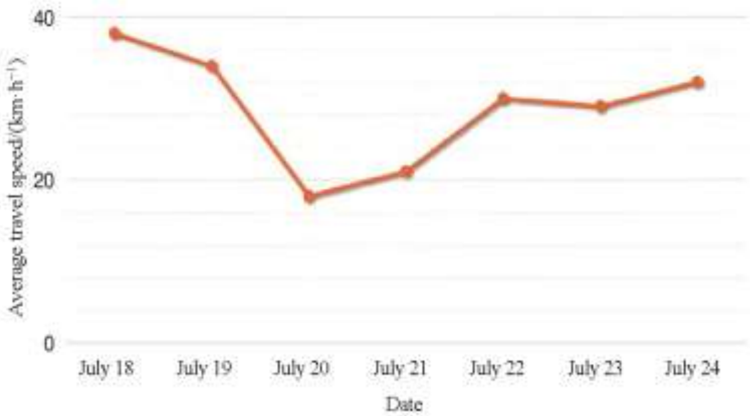

Fig. 3 Average roadway travel speed in Zhengzhou's main urban area before and after the July 20, 2021 torrential rainstorm

Source: Statistics from the Gaode Maps API platform.

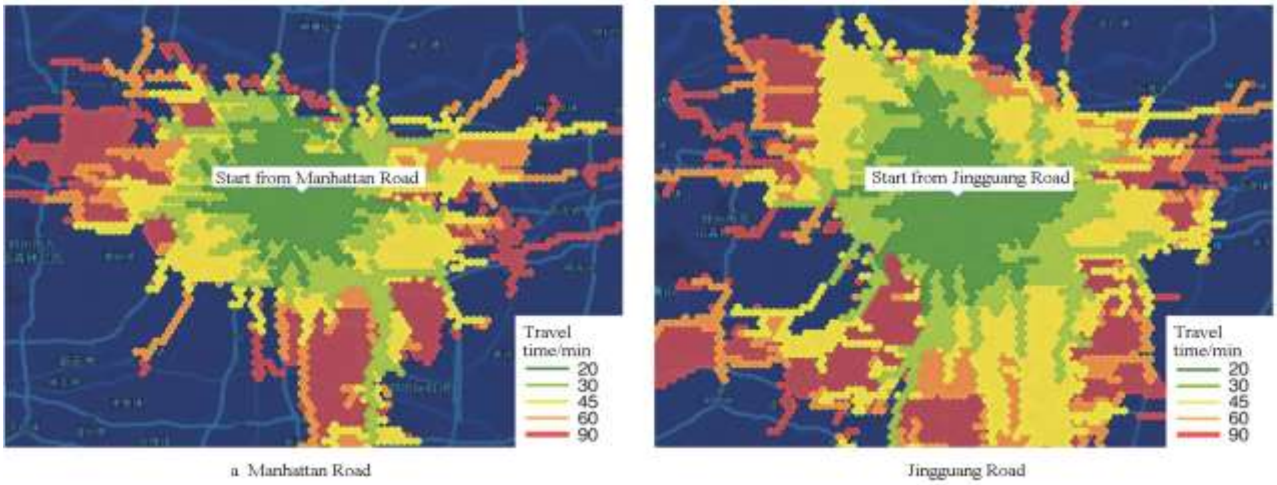

Fig. 4 Morning peak hour travel isochrones for key nodes in Zhengzhou's main urban area on July 23, 2021

Source: Statistics from the Gaode Maps API platform.

2.3.3 Late stage of the disaster

On July 26, the city fully resumed work and production. However, due to some sections of expressways remaining closed, widespread traffic restrictions, and incomplete restoration of traffic signal facilities, morning peak hour traffic congestion was severe. The average travel speed on roads during this period was 20.2 $km\ h^{-1}$, with a congestion index of 2.12 during peak hours (see Fig. 5). The average travel time during morning peak hours was 50 minutes, approximately 1.4 times longer than the usual 36 minutes.

2.4 Categories of road risk areas

Based on the analysis of the affected areas of transport facilities and road traffic conditions during the July 20, 2021 torrential rainstorm in Zhengzhou, categories of road risk areas under extreme rainfall conditions are identified as follows.

2.4.1 Traditional flat low-lying areas overlapping with elevated roadbeds of railways and highways

The eastern region of the Beijing-Guangzhou Railway is a traditional low-lying area with numerous waterlogging points. The elevated roadbeds of transport facilities such as the Beijing-Guangzhou Railway, Lanzhou-Lianyungang Railway, and Lianyungang–Khorgos Expressway create drainage obstacles. Consequently, during extreme rainfall events, large amounts of surface water cannot be discharged promptly, exacerbating the risk of road disasters (see Fig. 6).

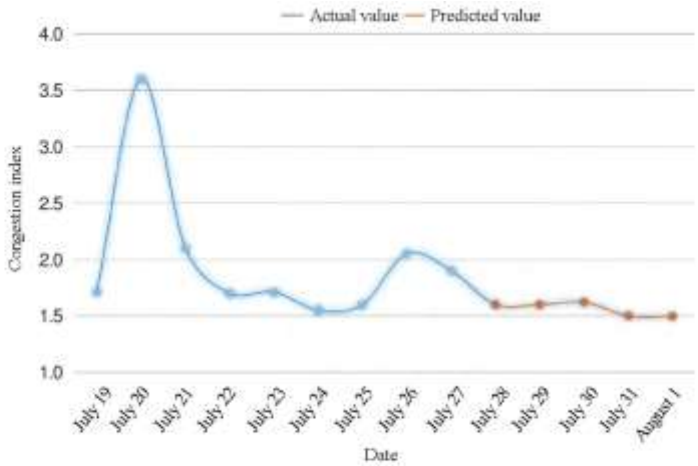

Fig. 5 Congestion index trends of morning peak hour traffic in Zhengzhou's main urban area before and after the July 20, 2021 torrential rainstorm

Source: Statistics from the Gaode Maps API platform.

Fig. 6 Distribution of areas with waterlogging hazards in Zhengzhou

Source: Reference [7].

2.4.2 Urban waterlogging-prone areas overlapping with traffic congestion

Risk areas vulnerable to waterlogging are primarily located along sections such as Jingguang Road, North Third Ring Road, Zhongzhou Avenue, and Longhai Road. These areas are prone to traffic congestion and pose significant challenges for traffic relief, increasing the likelihood of individuals becoming trapped in disasters (see Fig. 7). For example, both Jingguang North Road and Jingguang South Road are classified as high-risk areas for waterlogging. Jingguang North Road, adjacent to Zhengzhou Railway Station and surrounded by well-developed urban areas, experiences heavier traffic volumes and higher levels of congestion compared to Jingguang South Road. Consequently, during the torrential rainstorm on July 20, 2021, the damage to Jingguang North Road was significantly greater than that to Jingguang South Road.

2.4.3 Overlying areas of elevated expressway ramp and waterlogging-prone regions

Elevated expressways have a natural advantage in resisting waterlogging disasters, but their ramp exits are weak points that can easily lead to traffic paralysis during such events. During the July 20, 2021 torrential rainstorm in Zhengzhou, there were 16 severe waterlogging points on elevated expressway ramp exits, primarily concentrated on Zhongzhou Avenue.

Based on the 24-hour rainfall data from this event, this study employs Inforworks ICM software to simulate and assess waterlogging risks in Zhengzhou's main urban area [7]. Given that waterlogging depths exceeding 30 cm pose a significant risk to vehicle safety, ramp exits with such depths are classified as high-risk points. Ramp exits with waterlogging depths between 15 cm and 30 cm are categorized as medium-risk points, while those with shallower waterlogging are defined as low-risk points. The simulation results indicate that elevated expressway ramp exits in the eastern area of Jingguang Road exhibit higher risks, particularly concentrated on the East Third Ring Road, North Third Ring Road, Zhongzhou Avenue, Longhai Road (old town section), and Jingguang Road (north section and old town section) [10] (see Fig. 8).

3 Emergency response strategies for urban road traffic

3.1 Improvement in the emergency access route network with a focus on top-level design

The emergency access route network serves as a transportation network for disaster emergency rescue, emergency shelter, and post-disaster emergency support. Key emergency support facilities, including transport hubs, command centers, and medical rescue centers, should be interconnected to meet the requirements of urban disaster response and rescue. Furthermore, verification should be conducted based on disaster prevention zones to ensure that each zone has at least one emergency access route.

3.1.1 Establishing a premium emergency access route network

The Standard for Urban Planning on Comprehensive Disaster Resistance and Prevention (GB/T 51327-2018) categorizes emergency support facilities into Class I, Class II, and Class III. To meet disaster prevention needs, cities should prioritize planning two tiers of emergency access route networks to ensure connectivity for Class I and Class II emergency support facilities. However, the severe destructiveness of extreme rainfall has damaged some Class I emergency support facilities in Zhengzhou. Given that the urban emergency command system, lifeline system, emergency material transportation system, and other critical systems still rely on the emergency access route network for large-scale spatial movement within the city, it is essential to establish a premium emergency access route network based on the Class I emergency access route network to meet urban emergency disaster prevention requirements under extreme weather conditions.

a Distribution of waterlogging levels

b Distribution of traffic congestion

Fig. 7 Distribution of urban waterlogging levels and areas with traffic congestion

Source: Reference [7] and statistics from the Gaode Maps API platform.

Fig. 8 Risk evaluation of elevated expressway ramps during the July 20, 2021 torrential rainstorm in Zhengzhou

Source: Reference [10].

The overall goal of the premium emergency access route is to ensure the basic operation of urban lifeline engineering under extreme rainfall conditions. Taking Zhengzhou as an example, the disaster prevention capacity of the premium emergency access route should meet the standard for coping with intense bursts of rainfall similar to those experienced during the July 20, 2021 torrential rainstorm. Specifically, the drainage capacity of key nodes (such as entrances and ramp exits) should be strengthened to withstand a once-in-200-year rainfall event, which is the waterlogging control standard for the main urban area. Additionally, temporary waterlogging prevention equipment and emergency control measures should be implemented to respond effectively to extreme rainfall events.

3.1.2 Categories of emergency support infrastructure for a premium emergency access route

As shown in Figure 9, there are a total of 363 emergency support facility points at various levels within Zhengzhou, including 95 Class I emergency support facilities, which account for about 26%, and 268 Class II emergency support facilities, accounting for approximately 74%.

The premium emergency access route should connect to Class I emergency support facilities. These Class I facilities provide critical support for essential emergency rescue activities such as regional and urban emergency command, healthcare, water supply, material reserves, firefighting, and other functions involving national and regional public safety. Their operations cannot be interrupted during disasters or must be immediately activated after disasters. Based on the specific planning of emergency support infrastructure in Zhengzhou, emergency support infrastructure for the premium emergency access route can be categorized into five types (Table 3).

3.1.3 Division of disaster prevention zones

As urban units for allocating disaster prevention resources and constructing effective disaster relief and evacuation systems, disaster prevention zones should meet the requirements of preventing disaster spread and organizing timely rescue and evacuation. Furthermore, the division of these zones should be coordinated with the urban functional layout and reasonably classified and delineated based on factors such as urban scale, spatial pattern, disaster impact, and risk characteristics. This paper primarily considers three key factors for the division of disaster prevention zones: disaster impact, organizational management, and rescue and evacuation.

① For the disaster impact, the division of drainage zones is primarily considered to ensure that the direction of water drainage is consistent within the same disaster prevention zone. ② For organizational management, zoning is conducted according to administrative divisions (sub-district-level) to facilitate unified command and coordination of emergency disaster prevention work as well as to carry out the overall allocation of emergency rescue supplies. According to Reference [10], the appropriate population size for a disaster prevention zone is 200,000 to 500,000 in urban areas and 30,000 to 100,000 in peripheral areas. ③ For the rescue and evacuation, cross-regional evacuation should be avoided with a focus on the allocation of emergency rescue forces within the zone. Disaster prevention zones are primarily set up according to transport mid-zones delineated by railways, highways, elevated urban roads, rivers, etc. Based on the above principles, Zhengzhou has been divided into 71 disaster prevention zones, including 20 in the main urban area (Fig. 10).

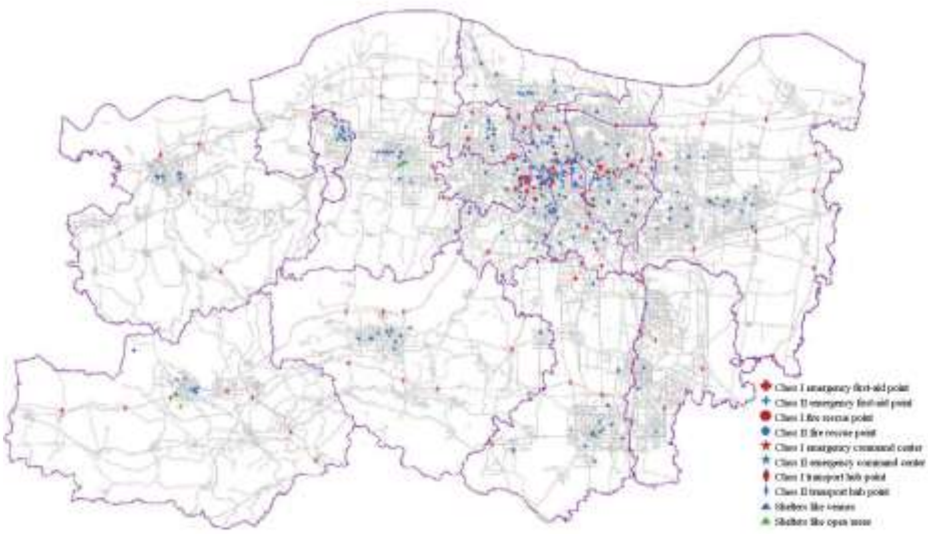

Fig. 9 Distribution of emergency support facilities in Zhengzhou

Source: Reference [10].

Table 3 Categories of emergency support infrastructure for major emergency access routes

Category	emergency support facilities
Emergency command center	Municipal-level emergency command center
Transport hub (facility)	Urban evacuation and rescue entrances
	Major transport hubs such as airports, ports, and railway stations that undertake significant disaster relief and rescue missions
Fire protection facilities	Fire command centers and special duty fire stations
Shelter facilities	Shelters in central urban areas
Healthcare facilities	Municipal and district-level shelters with emergency healthcare facilities

Source: Reference [10].

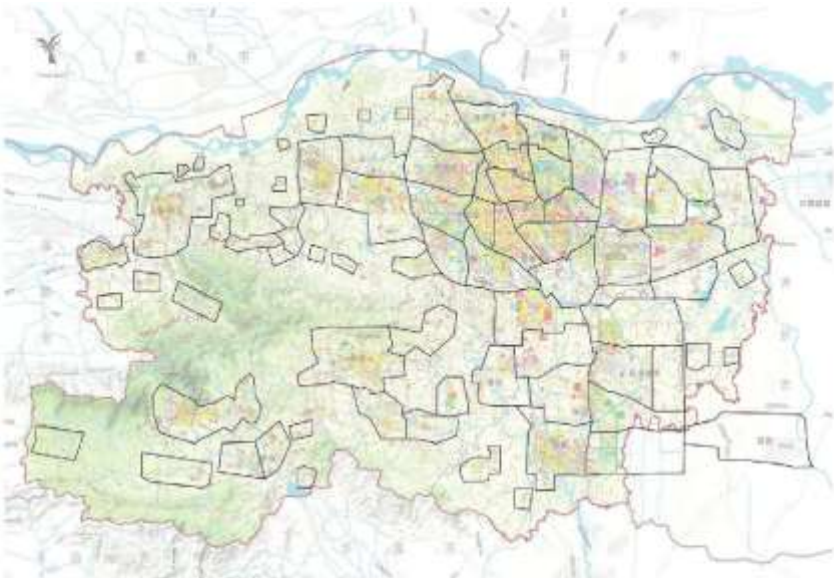

Fig. 10 Division of disaster prevention zones in Zhengzhou

Source: Reference [10].

3.1.4 Construction of emergency access route network

Considering factors such as road damage, the functional requirements of emergency support facilities, and the division of disaster prevention zones during the July 20, 2021 torrential rainstorm, the following basic requirements are proposed for constructing an emergency access route network in the context of extreme rainfall. Each urban district should have at least two emergency access routes for external transport. Major emergency support facilities should be interconnected to maintain their essential functions during major disasters. Each disaster prevention zone should have at least one emergency access route. Higher-grade highways should be prioritized for municipal emergency access routes. Emergency access routes should primarily consist of elevated roads, supplemented by traffic control measures, to ensure the smooth operation of urban lifeline channels during extreme rainfall events.

An emergency access route network has been constructed in the main urban area of Zhengzhou, featuring a layout of “Three Horizontals, Three Verticals, and Two Rings” (Fig. 11). Specifically, the “Three Horizontals” consist of the North Fourth Ring Road (from the Ring Expressway to the East Third Ring Road), Nongye Road, and Longhai Road. The “Three Verticals” include the West Fourth Ring Road (from Nongye Road to the Ring Expressway), Jingguang Road (from the North Fourth Ring Road to Longhai Road)–Zichen Road, and Zhongzhou Avenue. The “Two Rings” are formed by the Ring Expressway–Lianyungang–Khorgos Expressway–Beijing-Hong Kong and Macao Expressway and North Fourth Ring Road–West Fourth Ring Road–South Fourth Ring Road–East Third Ring Road.

3.2 Improvement in emergency evacuation plans and traffic management during disasters

Emergency evacuation is a crucial measure to reduce casualties during extreme rainfall events. During the July 20, 2021 torrential rainstorm in Zhengzhou, the lack of effective traffic guidance measures in the early stages resulted in a significant number of stranded vehicles and severe traffic congestion. This not only hindered rescue operations but also made it difficult for affected individuals to identify escape routes, leading to missed opportunities for optimal evacuation. It is imperative to improve emergency evacuation plans, particularly for areas with natural flood control weaknesses such as tunnels and sunken overpasses.

Taking the Jingguang Tunnel as an example, it spans a total length of 4.3 km and consists of three sections: Jingguang North Road Tunnel, Jingguang Middle Road Tunnel, and Jingguang South Road Tunnel. The Jingguang North Road Tunnel suffered the most severe damage, with its northern end connecting to the Elevated Jingguang Road and its southern end connecting to the Elevated Longhai Road via four ramps. Considering the ramp layout and adjacent roads, emergency evacuation plans for the Jingguang North Road Tunnel have been developed. When relevant departments issue warnings, traffic control measures will be initiated at downstream intersections of the tunnel exits to ensure rapid evacuation of vehicles inside the tunnel. The specific plan includes the following: Close the tunnel entrance and divert vehicles to the ground-level section of Jingguang Road; Prohibit vehicles from entering the tunnel via the ramps of the Elevated Longhai Road and guide them to the ground-level section; Continuously allow vehicles to exit via Zhongyuan Road, with a ban on west-to-east travel, and only right turns are permitted; Relieve traffic congestion at the Longhai Road exit by allowing right turns for quick exits, directing vehicles into the western section of Longhai Road (Fig. 12).

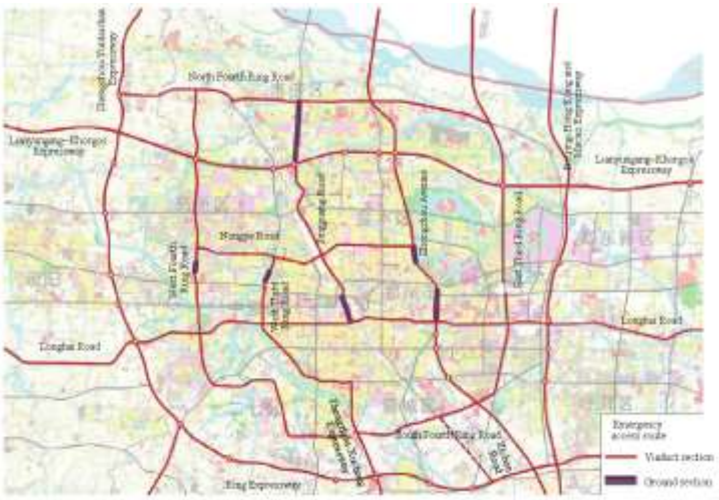

Fig. 11 Emergency access route network in Zhengzhou’s main urban area

Source: Reference [10].

Meanwhile, traffic control during disasters should be strengthened to ensure the effective implementation of emergency evacuation plans. The primary goal of traffic control during disasters is to allocate road system resources efficiently in both time and space, thereby ensuring smooth rescue and recovery efforts and sustaining the basic living needs of citizens [11]. Based on relevant experience from Japan, traffic control during disasters is divided into two stages: initial control and second-stage control. In the early stage of a disaster, initial control measures are implemented to guide vehicles out of the affected area as quickly as possible and prohibit non-local vehicles from entering emergency routes, ensuring that emergency rescue vehicles can access the disaster zone promptly. As the disaster escalates, the second-stage control plan is activated, allowing only rescue vehicles to pass through while prohibiting all other travel. Later, traffic control measures will be gradually lifted based on the evolving situation to restore normal urban order.

3.3 Planning of road drainage channels and detailed design

During the July 20, 2021 torrential rainstorm in Zhengzhou, short-term intense rainfall exceeded the collection capacity of the drainage network, leading to overflows and the formation of natural drainage channels on lower-lying roads. In response to the increasing frequency of extreme weather events and rapid urbanization, road surfaces function as overflow drainage channels for rainwater exceeding the pipe network's carrying capacity, playing a critical role in waterlogging control and hazard mitigation [12]. Therefore, the design of road drainage channels is particularly important during excessive rainfall events.

The selection of road drainage channels is typically determined during vertical planning, but traditional vertical planning often overlooks the need of road drainage. Therefore, when revising urban vertical planning, it is imperative to emphasize the integration with drainage and waterlogging control planning, enhance planning coordination, and comprehensively coordinate the layout of urban road drainage channels.

Regarding the cross-slope design of roads, according to the Code for Design of Urban Road Engineering (2016 Edition) (CJJ 37-2012), the road cross slope should comply with a standard range of 1.0% to 2.0%, with a preferred slope of 1.5% to 2.0% for express ways and areas with high rainfall. Ruan [13] proposed that a 2% cross slope results in a larger maximum water-carrying section, which enhances the drainage capacity of the road surface. Therefore, when considering the drainage channel function of non-traffic trunk roads, a cross slope of 2% is recommended where conditions permit.

Regarding the longitudinal slope design of roads, the Code for Design of Urban Road Engineering (2016 Edition) (CJJ 37-2012) stipulates that the longitudinal slope of motor

Fig. 12 Schematic diagram of emergency evacuation for the Jingguang North Road Tunnel in Zhengzhou

vehicle lanes on urban roads should be greater than 0.3%. In cases of special difficulties, serrated side ditches or other drainage facilities can be installed. However, the installation of serrated side ditches or gradient change points can easily create artificial low spots. When rainfall exceeds the drainage capacity of the rainwater pipe network, accumulated rainwater in these low spots cannot be discharged promptly, leading to waterlogging [14]. Therefore, the minimum longitudinal slope of road drainage channels should be greater than 0.3%, and drainage paths should be reasonably planned in conjunction with waterlogging control zones.

4 Conclusions

Enhancing the urban road traffic emergency and disaster prevention capabilities is a systematic project during extreme rainfall. A reliable, efficient, and flexible transportation system is crucial for ensuring the normal operation of cities during extreme weather or other emergencies, with road traffic playing a key role. Taking the July 20, 2021 torrential rainstorm in Zhengzhou as an example, this paper analyzes and assesses the damage to road facilities and waterlogging risks. It highlights that areas, where traditional flat low-lying areas overlap with elevated roadbeds, urban waterlogging-prone zones, coincide with traffic congestion, and ramp exits on elevated expressways are particularly vulnerable during extreme weather events. These areas

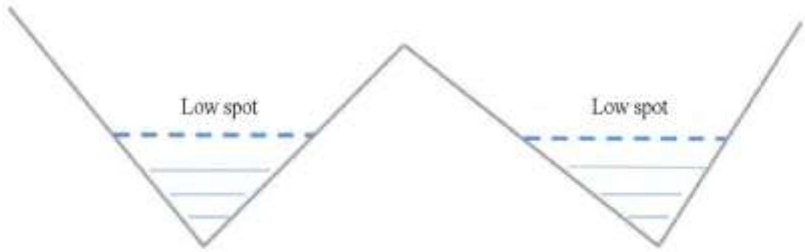

Fig. 13 Illustration of longitudinal slope of serrated roads

Source: Reference [14].

should be prioritized for treatment and control in the next step. Under conditions of excessive rainfall, urban road traffic should prioritize ensuring the normal operation of the city's lifeline projects as the primary goal. Emphasis should be placed on top-level planning and design, strengthening traffic management during disasters, formulating targeted emergency evacuation plans based on the city's characteristics, and enhancing the planning and design of road drainage channels in conjunction with traditional rainwater drainage networks to improve the resilience of urban traffic in the face of extreme weather.

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