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A Study on the Accessibility of the Emergency Medical Services for Urban Kindergartens and Nursing Homes Based on Urban Pluvial Flooding Scenarios

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Abstract: Vulnerable groups such as children and the elderly are the focus of emergency medical rescue during urban pluvial floods. Taking the Erqi District of Zhengzhou City as an example, the SCS-CN model and Chicago rainfall model are used to simulate pluvial flooding based on the comprehensive consideration of urban rainfall, runoff, topography, and drainage. Additionally, the accessibility of emergency medical aid for kindergartens and nursing homes is evaluated in the Erqi District of Zhengzhou under different pluvial flooding scenarios using GIS network analysis technology. The results showed that the number of kindergartens and nursing homes without timely access to emergency medical rescue increased with the increase in precipitation return periods. Under the 500-year and 1000-year pluvial flooding scenarios, kindergartens and nursing homes that can obtain emergency medical rescue had delayed response times. Furthermore, with the increase in the precipitation return periods, both the number and delay time of kindergartens and nursing homes significantly increased. The accessibility and delay time of emergency medical rescue in kindergartens and nursing homes were determined by the intensity of pluvial flooding (including inundation area and depth), road traffic conditions, and the number and location of medical institutions, nursing homes, and kindergartens. The research results can provide a scientific basis for improving the refinement level of urban flood disaster management and emergency response services.

Keywords: urban pluvial flooding; scenario simulation; emergency medical rescue; spatial accessibility; delay time; GIS

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1. Introduction

Under the background of global warming, extreme weather and climate events occur frequently. In particular, the frequency and intensity of extreme precipitation events have shown a significant increasing trend, leading to an increased risk of urban pluvial flooding disasters [1,2]. In addition, with the continuous advancement of China's urbanization process, the urban population and social wealth continue to increase, problems related to urban pluvial flooding in cities are becoming more prominent, and the losses caused by urban pluvial flooding disasters are also increasing [3,4]. In recent years, serious urban pluvial flooding disasters have affected the service functions of urban traffic and caused significant casualties and economic losses in more than 62% of large- and medium-sized cities in China. For example, the urban waterlogging caused by the rainstorm in Beijing on 21 July 2012, the extreme rainstorm in Wuhan on 6 July 2016, the heavy rainstorm in Guangzhou on 22 May 2020, and the pluvial flooding in Zhengzhou on 20 July 2021 not only resulted in serious casualties and economic losses, but also caused traffic disruption, affected urban road accessibility, and disrupted the normal travel of urban residents. More importantly, the efficiency of emergency services for key public service facilities such as medical aid, public security, and firefighting may be reduced or even paralyzed [5–7]. Therefore, under the background of the increasing risk of urban pluvial flooding, effectively improving the emergency response capacity of key public service facilities in cities and minimizing the impact of flood disasters on the economy and society has become a crucial issue that people are highly concerned about and urgently needs to be addressed by all sectors.

In recent years, spatial accessibility measurements have received more and more attention. Geographic information system (GIS) technology is widely used to evaluate the traffic accessibility of public service facilities such as hospitals, firefighting stations, and public security centers. Spatial accessibility is one of the important indicators for measuring the rationality of spatial allocation of various service facilities [8]. The evaluation of medical service accessibility has become key in measuring the balance and rationality of medical resources, optimizing the allocation of regional medical resources, and ensuring the fairness and efficiency of medical and health services [9]. A variety of models and methods have been applied to measure the spatial accessibility of urban medical services, such as the shortest path method based on GIS network analysis, two-step mobile search method, buffer analysis method, and gravity model method [10–12]. Shi et al. [13] selected the central urban area of Shanghai Outer Ring as the research area and the tourist attractions as the research object. They evaluated the spatial accessibility of the emergency response of key public service departments (120) in urban areas under current and future river flood scenarios with different precipitation return periods using pluvial flooding scenario simulation and the GIS network analysis method, which provides a typical case for urban tourism emergency management. Somenahalli et al. [14] measured the accessibility of the elderly to basic services (including hospitals) based on the start-to-end (O-D) time cost matrix of GIS network analysis. Hu et al. [15] assessed the accessibility of emergency medical services based using the 2-step floating catchment area (2SFCA) method, and found that road congestion had a negative impact on such accessibility. Luo et al. [16] employed the enhanced 2-step floating catchment area (E2SFCA) method to measure and analyze the spatial accessibility of medical services for the elderly in Wuhan, China.

Existing studies have focused on the impact of pluvial flooding disasters on the accessibility of public services, such as medical services (120) and public security (110). However, most of them determine the service scope of public institutions based on GIS network analysis tools such as ‘service area’ or ‘nearest facility point’. Relatively few studies have combined pluvial flooding scenarios with traffic networks to evaluate the accessibility of urban public services [17]. In addition, some special institutions, such as kindergartens and nursing homes, have not received enough attention in the study of public services’ accessibility. The focus of flood relief and protection should be on vulnerable groups such as children and the elderly. From the terrain point of view, the southwest is high, the northeast is low, the terrain is undulating, and the ravines are crisscrossed. The average altitude of the whole region is 177.9 m. With the rapid economic and social development, the urbanization rate of the Erqi District continues to rise, there was an expansion of urban ground hardening area, infiltration capacity decreased, and surface net discharge and runoff intensity increased, resulting in frequent flood disasters in recent years. Therefore, this paper takes the Erqi District of Zhengzhou City as an example and focuses on nursing homes and kindergartens in the Erqi District of Zhengzhou city as research objects. By combining the simulation results of urban pluvial flooding scenarios with the road network, the emergency medical response capabilities of nursing homes and kindergartens under different pluvial flooding scenarios were evaluated based on GIS network analysis tools. Firstly, Zhengzhou rainstorm intensity formula and Chicago design storms were used to calculate rainfall under different precipitation return periods. Then, the surface runoff was simulated under different precipitation return periods based on the SCS-CN model, and the flood inundation depth and area were simulated using the GIS local equal volume method. Finally, the spatial accessibility of medical services in kindergartens and nursing homes in the Erqi District of Zhengzhou City was calculated using the shortest path algorithm of GIS network analysis to provide a reference for disaster prevention and mitigation and the optimization of the layout of nursing homes and kindergartens in the Erqi District of Zhengzhou City.

2. Materials and Methods

2.1. Study Area

Zhengzhou, the capital of Henan Province, is a megacity city in central China, located in the south of the North China Plain and the lower reaches of the Yellow River. It spans the Yellow River and the Huaihe River basins with a total area of 7567 square kilometers and a permanent population of 12,742 million (at the end of 2021). In recent years, with the rapid development of urbanization in Zhengzhou City, the increase in impervious surfaces has led to a decrease in infiltration and an increase in surface runoff. At the same time, the decrease in the river network has increased the risk of urban pluvial flooding [18].

The Erqi District is one of the central urban areas of Zhengzhou (113°30′~113°41′ E, 34°36′~34°46′ N), located in the southwest of the center of the main urban area of Zhengzhou City. The terrain slopes change from high in the southwest to low in the northeast. It has a north temperate continental monsoon climate with simultaneous rain and heat, and an average annual precipitation of 640 mm. The total area of the Erqi District is 156.2 square kilometers, with a built-up area of 36.25 square kilometers. At the end of 2021, the Erqi District had jurisdiction over 17 streets and 1 town, with a permanent population of 1.0632 million people and an urbanization rate of 91.05%. The location of the study area is shown in Figure 1.

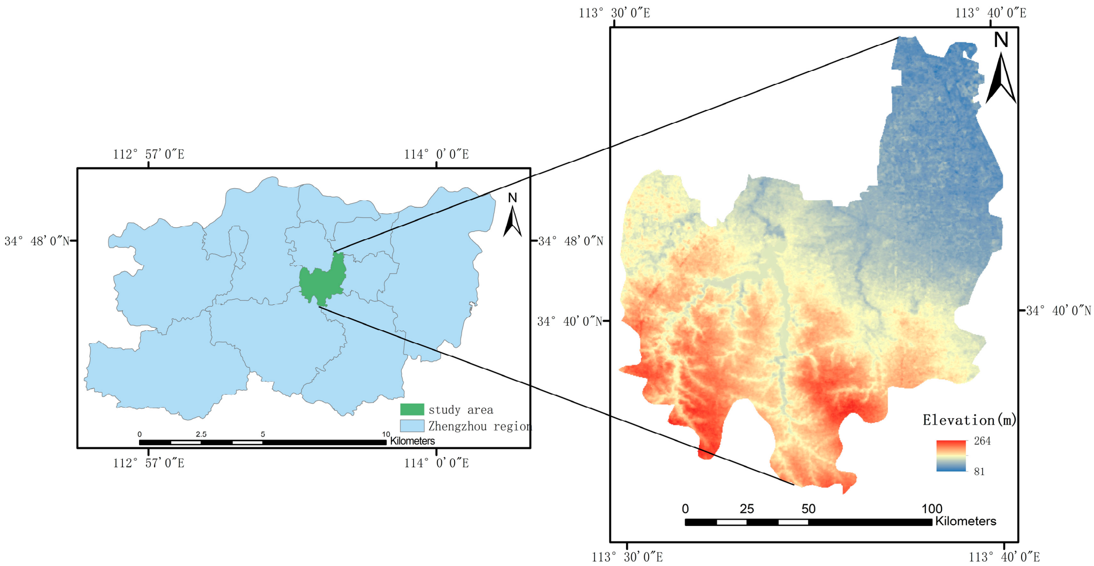

Figure 1. The location of the study area.

2.2. Research Data

The research data mainly include precipitation data, road network data, digital elevation data, and location data of public service facilities such as medical institutions, kindergartens, and nursing homes. The Chicago design storms and Zhengzhou rainstorm formula were used to simulate precipitation for different precipitation return periods. Remote sensing data (Landast8-OLI_TIRS 30M) and digital elevation data (GDEMV3 30M) were obtained from the geospatial data cloud website (https://www.gscloud.cn/ (accessed on 6 January 2023)). The road network vector data were obtained from the OpenStreetMap website (https://www.openstreetmap.org (accessed on 6 January 2023)). With reference to Zhengzhou urban planning and management technical regulations, and based on the actual road conditions in the Erqi District of Zhengzhou City, the grade and speed limits for urban roads were set as follows: motorways at 120 km/h, trunk roads at 80 km/h, primary roads at 60 km/h, secondary roads at 50 km/h, and tertiary roads at 30 km/h. The

WGS 1984 World Mercator projection coordinate system was used for both digital elevation model (DEM) data and road vector network data.

The information for urban medical institutions, nursing homes, and kindergartens was extracted from the Zhengzhou Municipal People's Government, Zhengzhou Municipal Education Bureau, and Zhengzhou Municipal Health Commission. Combined with the relevant data on the service capacity of the main medical and health institutions in the Erqi District, Zhengzhou City, 12 level-II or higher public medical institutions with emergency services capacity, 139 kindergartens, and 27 nursing homes have been maintained. Map Location was used to batch convert the address to latitude and longitude. The ArcGIS (10.2) data management tool and its conversion function were used to load it onto the layer. Figure 2 shows the remote sensing image of the study area (a), land-use types with a resolution of 30 m (b), and the distribution locations of public service institutions, kindergartens, nursing homes, and road types.

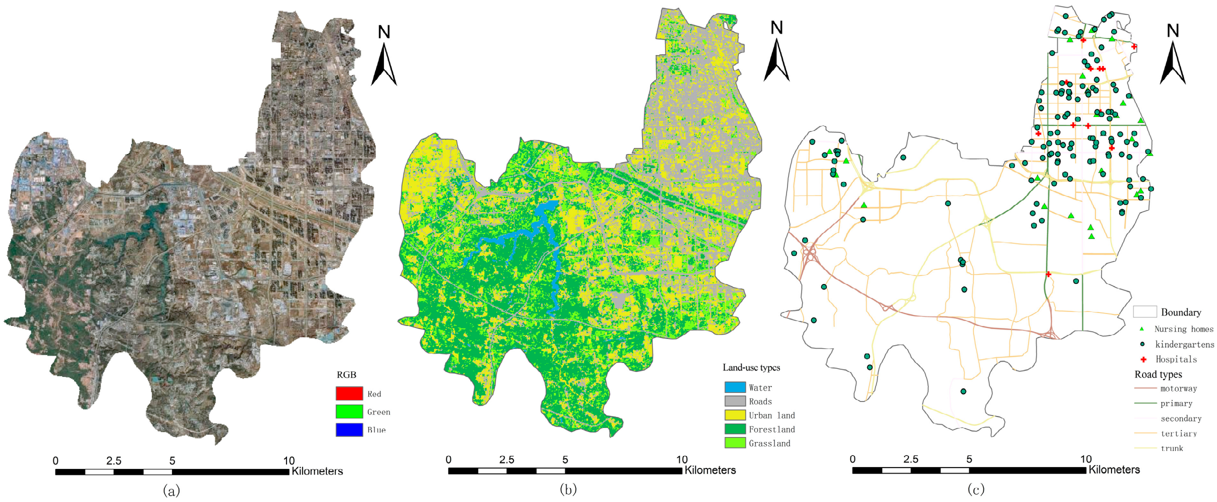

Figure 2. Schematic of study area: (**a**) Remote Sensing Map; (**b**) Land Use Types in Erqi District of Zhengzhou City; (**c**) the location of public service institutions, kindergartens, nursing homes, and road types.

2.3. Method

The methods used in this study were divided into four steps: data preprocessing, rainfall runoff calculation based on SCS-CN model, flood inundation analysis based on non-source flood, and equal volume method; the shortest path algorithm in GIS network analysis was used to measure the accessibility of the emergency medical services in urban kindergartens and nursing homes under different pluvial flooding scenarios. The specific technical route is shown in Figure 3.

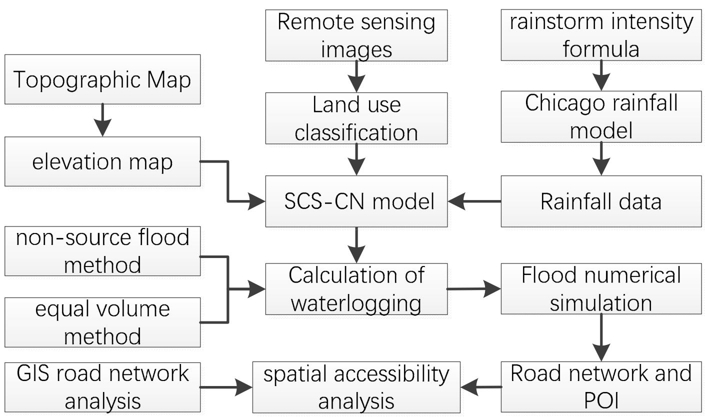

Figure 3. Technology road map.

2.3.1. Numerical Flood Simulation

The study selected the Erqi District of Zhengzhou City, which has relatively consistent geographical characteristics. Therefore, it was assumed that the spatial distribution of precipitation was uniform. Based on the Zhengzhou precipitation intensity formula compiled by the Central South China Municipal Engineering Design Institute, the Chicago rainfall model was used to design the rainstorm process. Short-duration precipitation with return periods of 100 years, 500 years, and 1000 years was calculated. The time interval was set at 1 min, and the total precipitation duration was 60 min [19,20]. The formula is as follows:

$$q = \frac{167\mathrm{A}(1 + \mathrm{Clgp})}{(\mathrm{t} + \mathrm{b})^{\mathrm{n}}} \tag{1}$$

where q is the precipitation intensity, mm/min; t is the duration of precipitation, min; and p is the return period, year. A, c, b, and n are all constants. According to the rainstorm intensity formula of Zhengzhou compiled by the Central South China Municipal Engineering Design Institute, A, c, b, and n are 3073, 0.892, 15.1, and 0.824, respectively.

By substituting the above parameters, the rainfall of three different pluvial flooding return periods in Zhengzhou City was obtained.

The Soil Conservation Service Curve Number (SCS-CN) model is a small watershed flood model proposed by the Soil Service of the United States Department of Agriculture, which is mainly composed of the water balance equation and two fundamental hypotheses [21,22]. The SCS-CN model reflects the inundation range of a river network and water system by accounting for various factors (e.g., rainfall, soil type, land-use pattern, and runoff).

$$\mathrm{P} = \mathrm{I_a} + \mathrm{F} + \mathrm{Q} \tag{2}$$

$$\frac{\mathrm{F}}{\mathrm{S}} = \frac{\mathrm{Q}}{\mathrm{P} - \mathrm{I_a}} \tag{3}$$

where Q is the direct runoff (mm); P is the total precipitation (mm); F is the actual infiltration amount; S is the potential maximum retention (mm); and $I_a = \lambda S$, λ is the initial loss rate. Under the condition of average runoff, the standard value of λ is 0.2 [23,24]. Combining Formulas (1) and (2), the surface runoff calculation formula of SCS-CN model can be established:

$$\mathrm{Q} = \frac{(\mathrm{P} - \mathrm{I_a})^2}{\mathrm{P} - \mathrm{I_a} + \mathrm{S}} \text{ for } \mathrm{P} > \mathrm{I_a};\ \text{otherwise } \mathrm{Q} = 0 \tag{4}$$

The calculation formula for S value is:

$$\mathrm{S} = \frac{25400}{CN} - 245 \tag{5}$$

where CN is the curve number, which is related to the underlying surface of the land, soil conditions, hydrological conditions, etc. The larger the CN value, the higher the runoff capacity, and the range of variation is $0 \leq CN \leq 100$. Referring to the CN value table in Chapter 9 of the National Engineering Manual, the CN value of the Erqi District of Zhengzhou City under normal conditions (AMCII type) was determined.

Due to the land-use types in each region being different, the area weighted average method was used to calculate the CN value [25]. The calculation formula is as follows:

$$CN = \mathrm{f_1} \times CN_1 + \mathrm{f_2} \times CN_2 + \mathrm{f_3} \times CN_3 + \mathrm{f_4} \times CN_4 + \mathrm{f_5} \times CN_5 \tag{6}$$

where $f_1 \sim f_5$ represent the area proportion of different land-use types; CN, $CN_1 \sim CN_5$ represent the composite CN value and the CN value of different land-use types, respectively.

In runoff analysis, the drainage capacity of the city should be considered. Based on the regulations of the urban planning management technology and the actual situation of Zhengzhou City, the actual drainage capacity of the Erqi District drainage network was set as once a year (36 mm/h). Based on the elevation data of the study area, the D8 algorithm of ArcGIS hydrological analysis module was used to divide urban catchment areas. This process included depression filling, water flow direction extraction, river network calculation, watershed identification, sub-catchment division, and generation of catchment areas [26]. The local equal volume method of GIS was used to simulate the depth and area of flood inundation under different precipitation return periods based on the idea of dichotomy. The product of the difference between runoff and drainage and the area of the study area was the theoretical value of the total amount of waterlogging in the area [27]. The calculation formula is as follows:

$$\mathrm{W} = (\mathrm{Q} - \mathrm{V}) \times \mathrm{S} \tag{7}$$

where W is waterlogging volume; Q is the runoff volume; V is water discharge; and S is the catchment area. Since the process will get some smaller areas, a threshold can be set to merge areas smaller than the threshold into larger adjacent catchments.

2.3.2. Shortest Path Method

The shortest path method was used to calculate the shortest travel time by utilizing the network analysis function of ArcGIS software. Generally, the height of the exhaust ports on ordinary vehicles is about 25–35 cm from the ground. If the water depth exceeds 30 cm, it may cause the exhaust pipe to be submerged and result in vehicle breakdown or other failures. Therefore, this paper assumed that the emergency medical rescue vehicles cannot pass through a road section with a water depth of more than 30 cm and simulated the shortest path from urban public medical institutions to kindergartens and nursing homes. According to technical regulations for urban planning and management in Zhengzhou, roads were classified and the road speed limit S_0 was set. Considering that the road inundation depth caused by pluvial flooding can affect driving conditions, such as poor visibility and slippery roads, the above speed limit should be appropriately reduced further. That is, the shortest path algorithm based on GIS network was used to determine the traffic state and speed of each road section, covering all possible urban road traffic conditions. The shortest paths from hospitals to kindergartens and nursing homes were calculated, respectively, under different pluvial flooding scenarios [28]. The calculation formula of the final emergency medical ambulance speed S_r is:

$$S_r = \mathrm{A} \times S_0 \tag{8}$$

where S_0 is the standard vehicle speed in urban planning management technology regulation; S_r is the speed under different traffic conditions; and A is the effect of pluvial flooding on vehicle speed. In the process of pluvial flooding within 1 h, different road inundation depths have different influences on the rescue speed of medical institution vehicles. The driving speed was set according to different inundation depths. When the depth of road water was 0–10 cm (S_1), 10–20 cm (S_2), and 20–30 cm (S_3), A was 0.7, 0.5, and 0.3, respectively.

3. Result Analysis

3.1. Flood Inundation and Exposure Analysis

The simulation results of the inundation area and depth under different pluvial flooding scenarios in the Erqi District, Zhengzhou City are shown in Figure 4. As can be seen from Figure 4, with the increase in the precipitation return period, both the inundation depth and area increased gradually. With the increase in the precipitation return period, there was a corresponding increase in the number of medical institutions, kindergartens, and nursing homes located in the waterlogging area. Road waterlogging not only affects the speed of medical emergency vehicles, but also may cause impassability (when the water level on the road reaches 25–35 cm, which is both the height of the vehicle exhaust port and part of the city water road closure standards, emergency medical vehicles cannot pass safely). This requires the medical rescue vehicle to take a detour to the rescue site, which is inaccessible to those in deep water.

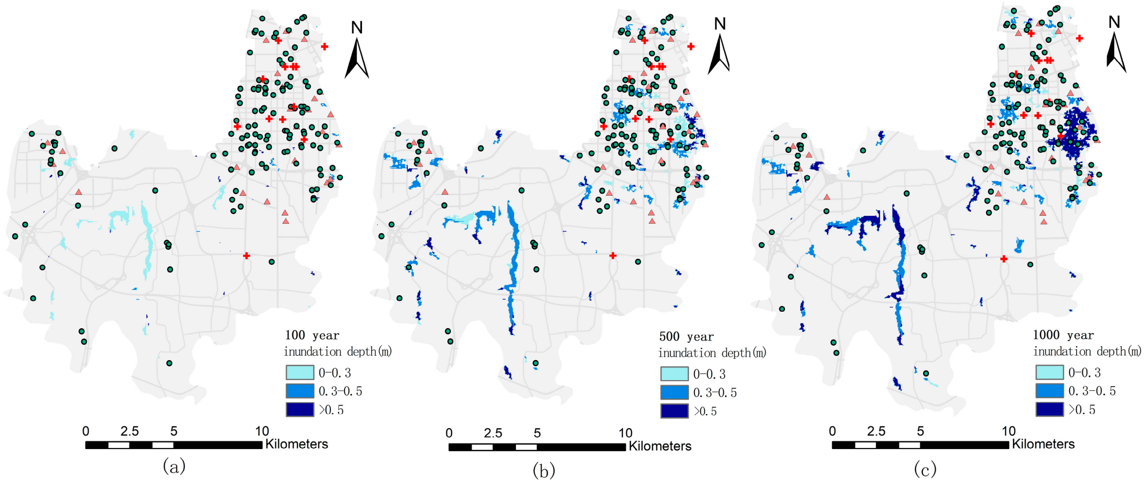

Figure 4. Simulation map of inundation area and depth under different pluvial flooding scenarios in the Erqi District: (**a**) the 100-year pluvial flooding scenario; (**b**) the 500-year pluvial flooding scenario; (**c**) the 1000-year pluvial flooding scenario.

Under the 100-year pluvial flooding scenario, the inundated area of the Erqi District was 3.37 km^2, but the area of inundation depth over 30 cm was small, only 0.43 km^2, which was mainly concentrated around Jiangang Reservoir and a part of Lianyun Road. The waterlogging layer of medical institutions, kindergartens, and nursing homes was obtained by overlaying the pluvial flooding inundation layer with distribution layers of nursing homes, kindergartens, traffic networks, and location layers of urban medical institutions. This can identify the roads, kindergartens, nursing homes, and medical institutions affected by waterlogging under different pluvial flooding scenarios as well as the depth of water accumulation under different pluvial flooding scenarios. Under the 100-year pluvial flooding scenario, there were no medical institutions, nursing homes, or kindergartens in the inundated areas.

Under the 500-year pluvial flooding scenario, the inundated area was 11.84 km^2, of which the area with inundated water depth exceeding 30 cm was 9.86 km^2, a significant increase compared with the 100-year pluvial flooding scenario. The inundated area was relatively scattered, indicating a zonal distribution around Jiangang Reservoir and on both sides of the Jinshui River, as well as irregular lumps or spots in other areas. Some sections of the low-lying Lianyun Road and Changjiang Road accumulated water of more than 50 cm, which not only poses a direct threat to public service facilities in the inundated area, but also seriously affects the normal passage flow, causing delays or interruptions in medical rescue services. Under the 500-year pluvial flooding scenario, 13 kindergartens and 1 nursing home located in the inundated area with a water depth of more than 30 cm were unable to receive emergency medical rescue services in time.

Under the 1000-year pluvial flooding scenario, the inundation area was 12.63 km^2, and the inundation area with a water depth exceeding 30 cm increased to 10.97 km^2 compared with the 500-year pluvial flooding scenario. The inundated areas were mainly located around the Jianggang Reservoir, at the intersection of Changjiang Road and Biyun Road, Lianyun Road, Xiangyun Road, and other sections. In some areas, the water depth exceeded 1 m. There was one hospital located in the area where the water depth was more than 30 cm. Due to the deep water surrounding the hospital, the emergency medical rescue vehicles were unable to be dispatched, resulting in a loss of emergency medical rescue service capacity, and paralysis of the emergency medical services. In addition, 18 kindergartens and 2 nursing homes were located in areas with water depth of more than 30 cm, making it difficult for them to receive timely emergency medical assistance services.

3.2. Emergency Shortest Path

The shortest path algorithm based on GIS network analysis (the shortest time between two points) did not consider the constraints of urban road traffic rules, such as traffic lights and turning lights. Additionally, the upper limit of water depth accessible to the road was set as 30 cm (at which the water depth would reach or exceed the height of the exhaust port of an ordinary medical ambulance, which would affect the safe passage of the vehicle). The shortest path from the hospital to the kindergarten and nursing home for rescue under different flooding scenarios was calculated. The driving speed at different water depths is shown in Table 1. The shortest path from medical institutions to kindergartens and nursing homes under different precipitation return periods is shown in Figure 5.

Table 1. Road speed limits in different classes of roads and speeds in different conditions.

Type	Motorway (km/h)	Trunk Road (km/h)	Primary Road (km/h)	Secondary Road (km/h)	Tertiary Road (km/h)
S_0	120	80	60	50	30
S_1	84	56	42	35	21
S_2	60	40	30	25	15
S_3	36	24	18	15	9

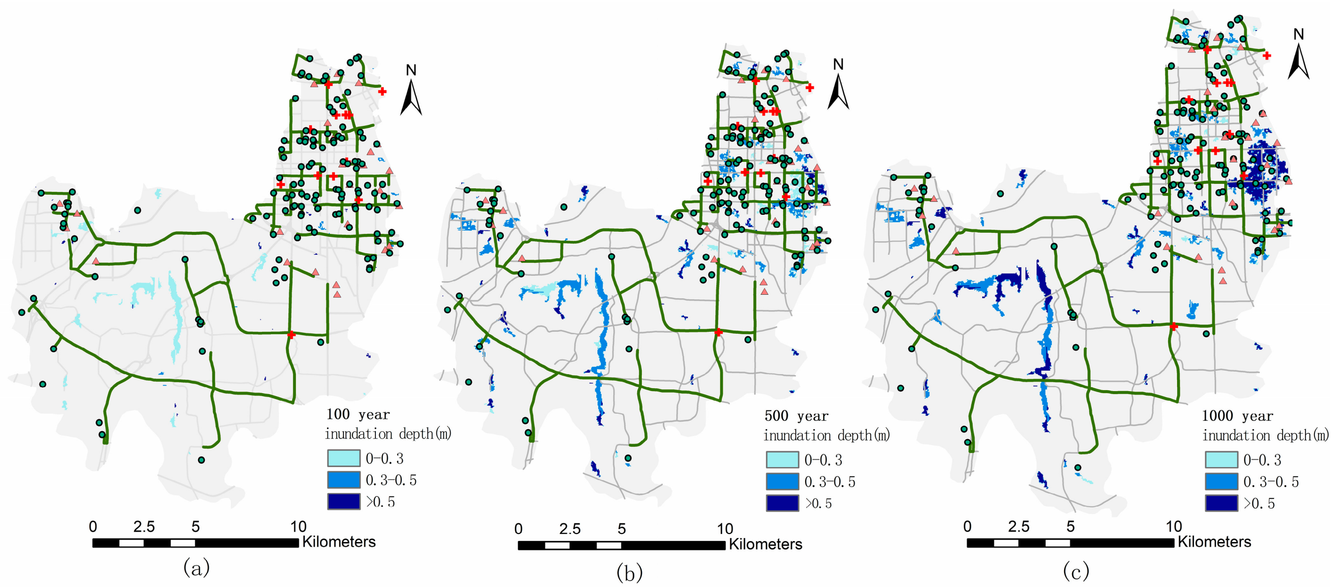

Figure 5. Closest facility analysis for medical institutions to kindergartens and nursing homes under different precipitation return periods: (**a**) the 100-year pluvial flooding scenario; (**b**) the 500-year pluvial flooding scenario; (**c**) the 1000-year pluvial flooding scenario.

Under the 100-year urban pluvial flooding scenario, the lengths of roads with water depths less than 10 cm, 10–20 cm, and 20–30 cm in the Erqi District of Zhengzhou City were 2.1 km, 0.69 km, and 0.51 km, respectively. The lengths of roads with water depths greater than 30 cm were 1.49 km, and there were no kindergartens or nursing homes located in an area with a water depth greater than 30 cm. As pluvial flooding had little impact on the emergency medical vehicles, all kindergartens and nursing homes in the study area were able to receive emergency medical services within 15 min. The shortest path from medical institutions to kindergartens and nursing homes is shown in Figure 5a.

Under the 500-year pluvial flooding scenario, the length of the inundated roads also increased. The lengths of roads with water depths less than 10 cm, 10–20 cm, and 20–30 cm were 1.56 km, 1.48 km, and 4.59 km, respectively. The length of roads with a water depth exceeding 30 cm increased to 23.88 km, some sections of which had a water depth greater than 50 cm, causing interruptions in road networks and resulting in prolonged travel times that seriously affected the accessibility of the emergency medical services. A total of 13 kindergartens and 11 nursing homes were situated in areas where the water depth exceeded 30 cm, impeding prompt access to emergency medical services. About 40% of kindergartens unaffected by accumulated water experienced delayed emergency medical services (rescue time exceeded 15 min), with an average delay time of 2.9 min and a maximum delay time of 8.2 min. About 26% of the nursing homes unaffected by waterlogging experienced delayed emergency medical services, with an average delay time of 0.85 min and a maximum delay time of 6.69 min. Due to road traffic interruption, emergency medical rescue vehicles had to take a detour. The fastest route from medical institutions to kindergartens and nursing homes is shown in Figure 5b.

Under the 1000-year pluvial flooding scenario, the length of the inundated roads in the Erqi District of Zhengzhou City further increased. The lengths of roads with water depths less than 10 cm, between 10 and 20 cm, and between 20 and 30 cm were 1.34 km, 1.49 km, and 1.87 km, respectively. The length of roads with a water depth exceeding 30 cm increased to 28.5 km. Additionally, in the eastern part of the Erqi District, some sections had a water depth exceeding 60 cm, which seriously affected the safe passage of emergency medical vehicles. As 18 kindergartens and 2 nursing homes were located in areas with a water depth exceeding 30 cm, emergency medical services may not be available promptly. Among the kindergartens and nursing homes that were not affected by waterlogging, only 16.55 percent of kindergartens and 70.3 percent of nursing homes had timely access to emergency medical services. The average delay time in kindergartens was 3.6 min, with a maximum delay time of 15 min. The average delay time in nursing homes was 2.8 min, with a maximum delay time of 7.53 min, which significantly increased compared with the 500-year pluvial flooding scenario. The shortest path from medical institutions to kindergartens and nursing homes is shown in Figure 5c.

4. Conclusions and Discussion

4.1. Conclusions

Based on the SCS-CN model and Chicago rainfall model, this paper studies the accessibility of emergency medical services in where kindergartens and nursing homes are located in the Erqi District of Zhengzhou City by utilizing numerical flood simulation and ArcGIS network analysis of the shortest path. The main conclusions are as follows: (1) With the increase in precipitation return period, the inundated area, water depth, and the length of the inundated road in the Erqi District of Zhengzhou City also increased. (2) Under the 100-year urban pluvial flooding scenario, medical institutions, kindergartens, and nursing homes in the Erqi District of Zhengzhou City were not located within the inundated area. All kindergartens and nursing homes could receive emergency medical services within 15 min. (3) Under the 500-year and 1000-year pluvial flooding scenarios, kindergartens and nursing homes were situated in inundated areas with water depths exceeding 30 cm, rendering them inaccessible to emergency medical services. Furthermore, as the precipitation return period increased, so did the number of nursing homes and kindergartens unable to receive emergency medical services. (4) According to the shortest path method (i.e., minimizing rescue time), under the pluvial flooding scenarios of 500-year and 1000-year return periods, rescue delays occurred in all kindergartens and nursing homes that had access to emergency medical services. Furthermore, as the precipitation return periods increased, both the number and delay time of delayed rescues for kindergartens and nursing homes also increased. (5) The accessibility of the emergency medical services in kindergartens and nursing homes under pluvial flooding scenarios in the Erqi District of Zhengzhou City was related to the distribution of medical institutions, topographic factors, traffic accessibility, and their own location.

4.2. Discussion

Urban medical services play a vital role in the public health and well-being of urban residents, particularly the emergency medical services for vulnerable groups, such as the elderly and children, during times of disaster. Taking the Erqi District of Zhengzhou City as an example, this paper studies the accessibility of the emergency medical services in kindergartens and nursing homes based on the actual data of medical institutions, kindergartens, nursing homes, and urban road networks based on simulating different urban pluvial flooding scenarios. The study found that more kindergartens and nursing homes were unable to access emergency services due to road disruptions as the return period of heavy rainfall increased. Therefore, government departments should take measures from multiple aspects to reduce the risk of urban pluvial flooding inundation for kindergartens and nursing homes, optimize medical service facilities and improve road accessibility, and comprehensively enhance the rescue capacity of emergency medical services. ① To improve the drainage capacity of regions, especially those prone to water accumulation, the drainage network of the Erqi District of Zhengzhou city should be rationally planned to increase its capacity to handle waterlogging. ② Existing medical resources should be fully optimized, and medical institutions must be strategically planned, distributed, and constructed in areas with inadequate healthcare resources. For example, increasing the personnel and equipment of existing medical institutions could enhance the capacity of emergency medical services. At the same time, more medical resources should be allocated to the south and west of the Erqi District of Zhengzhou, especially the Wangzhuang community and Shuimo community, to achieve a balanced and fair distribution of medical resources. ③ Rational planning and construction of roads around medical institutions and densely populated areas to increase the density of the road networks, thereby improving road accessibility. ④ Medical institutions, kindergartens, and nursing homes located in low-lying areas with water accumulation should be relocated to reduce the risk of flooding. ⑤ Measures should be taken to improve the accuracy of real-time forecasting of urban pluvial flooding, optimize the navigation system of emergency medical ambulance vehicles, and accurately capture real-time traffic status and road water information to minimize rescue delays.

This study attempts to analyze the spatial accessibility of the emergency medical services for kindergartens and nursing homes under different pluvial flooding scenarios. However, there are also the following deficiencies: (1) In this study, a unified reduction coefficient was used to calibrate the driving speed of medical ambulance vehicles at different water depths, without considering the impact of traffic congestion and human travel on their speed. (2) This study only considered the emergency response capability of internal medical institutions in the Erqi District of Zhengzhou and did not take into account the marginal effect of emergency medical service accessibility. (3) Due to the limitation of data acquisition and accuracy, the resolution of elevation data was 30 m $\times$ 30 m. The accuracy of the research data should be enhanced in the follow-up study. In addition, the submerged depth and range under different pluvial flooding scenarios were simulated based on the passive submerged method, without considering the problem of water flow connectivity. In the future, the non-source flood method and source flood method should be combined to improve the accuracy of flood area identification. (4) In addition to considering the depth of flood inundation, the impact of the duration and flow velocity on the accessibility of urban public services should also be considered.

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