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Influencing Factors and Solution Measures of Urban Flooding -- Taking Shanghai as an Example

Yuxi Yao

Suzhou Science and Technology Town Foreign Language High School, Suzhou, China
yaoyuxi1224@outlook.com

Abstract: Global warming has led to an increase in the frequency of extreme precipitation in various parts of the world. Extreme precipitation can easily lead to frequent urban flooding disasters, which bring serious harm to both the urban infrastructure and the daily lives of residents. Therefore, this paper takes Shanghai, a highly developed and densely populated metropolis, as an example, focusing on three important factors affecting urban flooding. It comprehensively analyzes relevant studies based on the urban drainage system, urban river network, and urban topography. This paper concludes that by upgrading the level of urban greening, building a smart platform, and building a sponge city, combined with today's ever-changing artificial intelligence technology, it is possible to scientifically prevent and control waterlogging in a more efficient and sustainable manner. This paper hopes to put forward relevant suggestions for the prevention and control of waterlogging in major cities in the future by organizing and analyzing relevant studies, thereby contributing to the development of more resilient urban environments.

Keywords: Precipitation, Waterlogging, Drainage System, Shanghai

1. Introduction

Greenhouse gas (GHG) emissions from combustion increase with urbanization. Greenhouse gases do not prevent solar radiation from reaching the surface, but they tend to absorb long-wave radiation emitted by the surface, making it difficult to dissipate heat. The increasing emissions of greenhouse gases (e.g., carbon dioxide, methane, etc.) further contribute to global warming, which has led to an increase in extreme precipitation events around the world. Accordingly, extreme precipitation and flooding events have increased in China [1]. In a bunch of cities, such as Shanghai, for example, they face extreme precipitation in summer. And because of today's global warming trend, cities are prone to urban flooding when faced with extreme precipitation caused by a combination of their own climate (e.g., typhoons, heavy rains, etc.) and global warming. Urban flooding undoubtedly brings numerous negative impacts. It not only affects the normal life of the residents, but also affects the agricultural output and crop harvests, and brings negative consequences in traffic operation and material transportation, which further affects the normal operation of the economy.

According to relevant research responses, the main causes of urban flooding are categorized into two groups: human factors and natural factors. Natural factors, including the surface runoff flow rate of the city affected by the slope of the terrain, the amount of soil infiltration, as well as the city itself, are located in the climate type of the average annual precipitation, rainfall intensity and so on. Under heavy rainfall conditions, surface runoff pools rapidly during precipitation, and the infiltration of soil

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and rock is not sufficient, so it is easy to accumulate water in low-lying areas of the city, resulting in flooding [2]. The plains and hills are areas prone to flooding because the flat terrain is not conducive to drainage. And rainwater gathers and accumulates, making it easy to produce large amounts of water. Moreover, in the event of extreme precipitation, the water level of rivers in the plains rises significantly, resulting in rain and flooding not being able to be smoothly discharged into the river through the difference in terrain, further increasing the risk of flooding [3].

At present, related scholars often assess the impact of flooding in a fixed area of the city based on entropy value method and the entropy weight method.

In the assessment of urban rain and flood vulnerability and resilience through the example of Guangzhou City, Yang Xiao et al use the entropy weight method to construct an evaluation model for environmental, social, economic, infrastructure, and other dimensions [4]. By setting the weights, the resilience index of Guangzhou City in the face of rain and flood disaster in various administrative districts is to be evaluated. From there, each district-level administrative area with strong coping ability and weak coping ability; those suffering small losses and those suffering large losses are categorized when flooding occurs.

There are various countermeasures for waterlogging, including engineering and non-engineering measures. For example, in the study of waterlogging in the Rongdong area of Xiong'an New Area, Hebei Province, Guo Lei et al proposed to implement both engineering and non-engineering measures [5]. They add engineering measures at the source and in the drainage process, and monitor the water operations in the eastern area by building a smart water platform to predict rain and flooding hazards in advance and reduce the risk of waterlogging.

The purpose of this paper is to analyze the influence of several factors affecting urban flooding on the risk of flooding in Shanghai based on the environment of Shanghai and related scholars' research. The author will propose relevant solution measures for the management of waterlogging based on the analyzed influencing factors, as well as suggestions and outlooks.

2. Overview of the study area

2.1. Basic information about Shanghai

This paper takes the city of Shanghai as the research object. Shanghai is located in the east of China, on the west coast of the Pacific Ocean, at the front edge of the Yangtze River delta in East China, with its longitude ranging from 120°52′ to 122°12′ E, and its latitude ranging from 30°40′ to 31°53′ N. The city is under the influence of the northern subtropical monsoon climate. Shanghai is under the influence of the northern subtropical monsoon climate, and the average annual precipitation ranges from 800 mm to 1450 mm, concentrated from April to October [6]. The city is divided into 16 districts, including Chongming, Baoshan, Jiading, Qingpu, Songjiang, Jinshan, Yangpu, Hongkou, Jing'an, Putuo, Changning, Huangpu, Xuhui, Minhang, and Fengxian.

As a mid-latitude coastal city, Shanghai faces the multiple impacts of the summer subtropical monsoon climate and typhoons, and is prone to experiencing extreme precipitation. In the past decade, there have been several urban flooding events, such as on July 25, 2021, when heavy rainfall occurred in Shanghai under the influence of Typhoon “YanHua”, and urban flooding occurred in Pudong, Fengxian District and other coastal administrative districts. The maximum precipitation amount reached 60 mm in one hour, and the cumulative precipitation in two hours had reached 100 mm. Shanghai, as one of the international financial cities and the largest economic center in China, faces the problem of waterlogging not only affects the lives of the residents but also affecting the trade flows and economic operations. Therefore, the scientific management of waterlogging in Shanghai is urgent.

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When extreme heavy precipitation occurs within the city of Shanghai, it can cause transportation disruptions, damage to city infrastructure (roads, buildings, power supply, etc.), and threats to the lives and property of residents. It can also result in stores being forced to close and trade flows being restricted. Moreover, during the flooding period, the pressure of flood prevention and relief increases, the drainage system of Shanghai will be damaged, and the expenses of arranging personnel to investigate and overhaul the system at a later stage will also increase the financial pressure on the local government. Overall, urban flooding will hinder the regional economic development of Shanghai [7].

2.2. Factors affecting flooding

Regarding the several factors affecting waterlogging in Shanghai, they include the design of the city's downspouts and drainage systems, the flood discharge capacity of the river network (e.g., Yangtze River and Huangpu River), the degree of hardening of the ground surface, and the topography of the city's terrain.

2.2.1. Sewage system

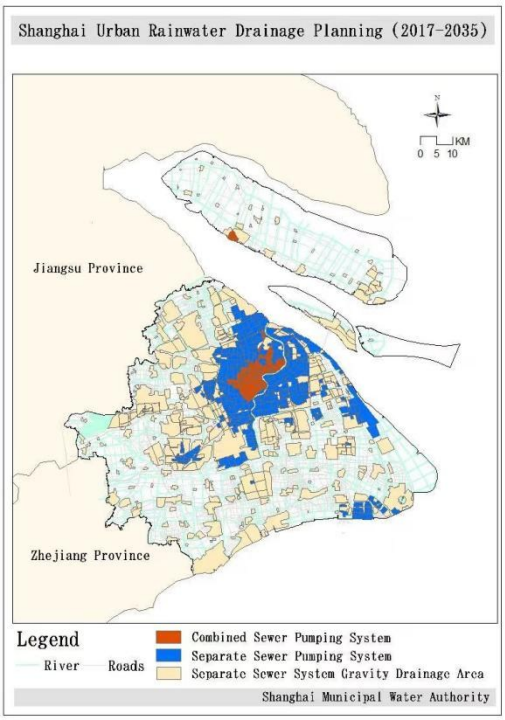


Figure 1: Distribution of drainage system in Shanghai city with combined flow system

There are currently 56 river-based overflow drainage systems constructed in Shanghai, with the diversion system as the main system and the combined flow system as a supplement. The total length of the combined flow drainage system is 1106.7 km [8]. Figure 1 shows the drainage plan of Shanghai for the combined flow system and diversion system, and the distribution of the river network in Shanghai. Shanghai's stormwater system now mainly exists in the following problems: First, the development of the city of Shanghai is early, the construction of the central city drainage system was completed in the 1990s. There are drainage network aging problems. Second, the water table in Shanghai is high, the pipeline is in a state of high water level operation. The drainage process is prone to be blocked. In addition, the drainage system was built when the precipitation is not as high as

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today's precipitation, which is under the influence of global warming intensification. And the drainage system is located in the old city, the rectification needs huge financial expenditure and difficulties, so the drainage capacity is lower than the intensity of precipitation, increasing the risk of urban flooding [9]. When facing the heavy rainfall, if the existing drainage network cannot properly deal with waterlogging, it will lead to rainwater concentration in the area with a dense pipe network, and even develop into an aggravating factor of urban waterlogging problems [10].

2.2.2. River network

The drainage network of Shanghai includes both the sewerage system and the river network in which the city itself is situated. Most of the river network in Shanghai belongs to the Huangpu River system, including Suzhou River, Chuanyang River and Dianpu River. The density of the river network in Shanghai is high, at 4.79 kilometer per square kilometer. As of 2022, the water surface rate of rivers and lakes in the city is around 10.30%, with Qingpu District having the highest rate (18.74%) and Jing'an District having the lowest rate (1.89%) [11]. Relevant studies have found that as the water surface rate of rivers and lakes in the drainage area increases, the capacity of the drainage system to drain and treat water and the regulatory capacity of rivers and lakes for urban flooding increase [12]. Nowadays, the water surface rate of rivers and lakes in Shanghai increases slightly year by year, and the rate increases from 10.11% to 10.30% between 2020 and 2022, and the regulatory capacity of the drainage system is also affected, perhaps reducing the risk of flooding [11].

2.2.3. Topography

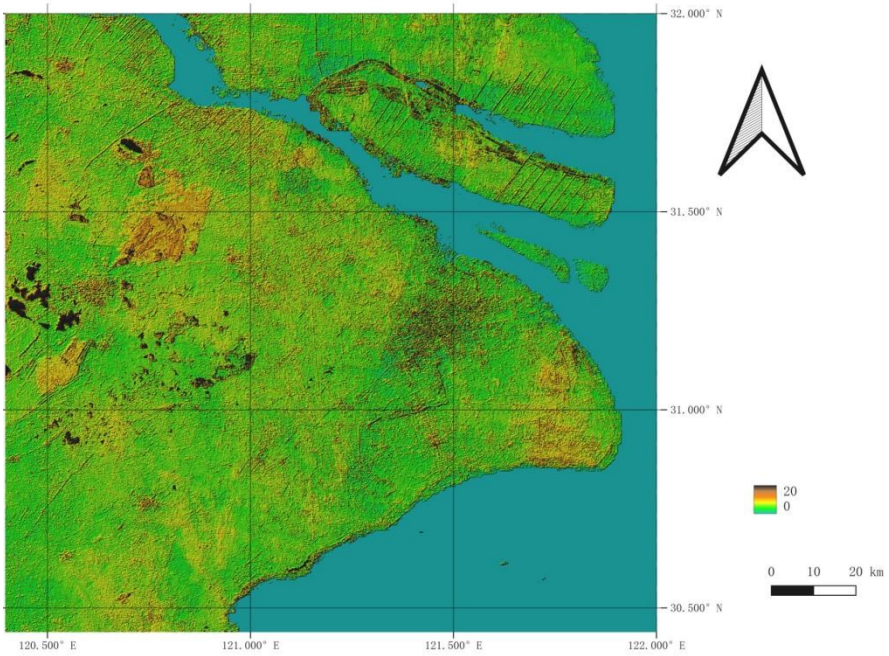


Figure 2: Shanghai elevation map

The city of Shanghai is at a low elevation, in the plains of the middle and lower reaches of the Yangtze River, and belongs to the cities bordering the sea. Plains dominate the territory of Shanghai, with only a few hills on the southwestern side. The average elevation of the city is about 4 meters, and the highest point is located in Dajin Mountain of Shanghai, which is only 103.4 meters above sea level. Figure 2 illustrates the elevation distribution of the city of Shanghai. From Figure 2, it can be seen

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that the average elevation of the city is extremely low, with only a slight increase in elevation in the eastern part of the city. The central part of the city has the lowest elevation and many tall buildings. Related studies have shown that the topography of the city has a significant effect on the occurrence of urban flooding. Topography affects the degree of surface undulation and roughness. A high degree of surface roughness can not only slow down the flow rate of surface runoff and increase the infiltration rate, but also impede the pooling of surface runoff, reduce the depth of waterlogging and alleviate the degree of waterlogging [10]. In Shanghai, the degree of surface undulation is low, and the vegetation coverage rate in the central city is also low. Moreover, as urbanization proceeds, the degree of hardening of the surface of Shanghai as well as the increase in impermeability, further reduces the natural infiltration capacity and vegetation coverage. Surface runoff is rapidly discharged into the river network, resulting in increased pressure on river and lake drainage and a greater risk of flooding.

3. Solution measures

Because of the previously described factors affecting flooding in Shanghai, urban flooding can be mitigated in three aspects: upgrading the level of urban greening, building a smart platform, and building a smart city.

3.1. Enhance the level of urban greening

At the early stage of Shanghai's construction, urban greening was faced with the following problems: low per capita area of public green space, low greening rate, uneven distribution, low quality, etc. [13]. In the past 30 years, the greening level of Shanghai has been generally improved substantially. As of 2023, the greening area of Shanghai has reached 1285.2 square kilogram, with a forest coverage rate of 18.81% [14]. In order to further reduce the risk of flooding and enhance the city's ability to regulate rain and floods, the greening level of Shanghai's central city needs to be further improved. The construction of roof gardens can be a major enhancement approach.

Rooftop garden is a form of spatial greening and beautification based on buildings, to beautify the city. This helps increase water storage, regulate the climate, and enhance the green coverage area [15]. In the 1880s, Shanghai began to introduce rooftop greening technology, the first batch of rooftop greening was built in HuaTing Hotel. Since then, the Shanghai Municipal Government has taken “greening at every turn” as its goal, and has carried out vegetation greening on urban buildings and public facilities, as well as constructed rainwater recycling systems. While improving people's living standards, it reduces carbon emissions and helps to control rain and flooding [16].

3.2. Intelligent platform construction

China's State Council on the General Office of the State Council on strengthening the implementation of urban flood management opinions clearly put forward the solution to strengthen the construction of an intelligent platform. The construction of the smart platform includes: the construction of data monitoring stations at major flooding points during the past years in order to build real-time monitoring of rain and flooding; the prediction of flooding risk through satellite data and weather station forecasts to improve the accuracy of the alarm and warning; and the requirement that the city combine rain and flooding data with the basic platform of the city's information model, so that disaster prevention and mitigation can be adapted to local conditions [17]. Shanghai has built a smart water management platform, the need to improve and build the following systems. First, the “smart river network” management service system, the dense river network in Shanghai, the need to set up more data monitoring instruments, to promote unmanned monitoring technology, and comprehensively improve the detection of river and lake ecosystems. The second is the “intelligent flood control”

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emergency command system, according to the guidance of real-time data, rescue and relief at various flooding points to ensure that the damage is minimized [18].

3.3. Sponge city construction

In recent years, China has been committed to sponge city construction. Sponge city is a figurative expression that refers to the city can be like a sponge, through strengthening urban planning and construction management, giving full play to the role of buildings, green spaces and squares, urban roads, river and lake water systems in absorbing, storing and seeping and slowing the release of precipitation [19]. During the rainy season or rainfall, it can promote rainwater infiltration and replenish urban groundwater. In the dry season, the stored water can be utilized to alleviate water scarcity. The construction of a sponge city in Shanghai helps to increase the infiltration rate of rainwater on the surface during high-intensity rainfall in summer, reducing surface runoff and groundwater accumulation and effectively reducing the risk of flooding. At the same time, it reduces the drainage pressure of Shanghai's drainage pipe network, delays the peak of river runoff, and improves the drainage status of Shanghai's pipe network and river network. Taking a regional water resource utilization project in Shanghai as an example, the area realizes the collection, storage and utilization of rainwater through bioretention facilities and permeable paving technology. Calculation results show that the total rainwater utilization rate of the project can reach 50.2% [20].

4. Recommendation and outlook

4.1. Limitations

When planning for flood control and flood prevention in Shanghai through the above measures, certain problems and challenges are still faced.

Roof gardens cover a small area in the city, and plant maintenance faces technical difficulties. And it will increase the load-bearing capacity of the reinforced concrete structure on the roof of urban buildings, and the roof is subjected to increased stress, which may cause deformation of the roof in the center of the building [21].

The construction of the smart platform requires a large amount of technical support and needs to be combined with a large amount of data to be analyzed. In addition to arranging data collection equipment at urban flooding points, it is also necessary to obtain satellite data, which is time-consuming and slightly less efficient. Strengthen the monitoring of the river network pipe network, and also need more advanced technology iteration.

The completion of the sponge city is time-consuming, capital consumption and need to take into account the balance of the city's various indicators.

4.2. Outlook

While building three-dimensional green roofs, develop automated irrigation technology, intelligent water storage and drainage. At the same time as reducing the energy spent on maintenance, reduce the building roof load-bearing. Nowadays, the development of artificial intelligence is changing rapidly, and it is recommended to combine artificial intelligence technology with analysis in the construction of the intelligent water platform, which can greatly improve the operational efficiency of the platform. Through real-time remote sensing data, rainfall intensity and time are predicted in advance, and the surface runoff flow direction and rainwater infiltration rate during rainfall are predicted to provide more accurate forecasts. And popularize the relevant platform to the public, combined with the masses, to do a good job of flood prevention and flood control measures. To build sponge cities, it is recommended to strengthen the cultivation and utilization of highly skilled

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personnel and implement professional teams. By analyzing and studying the current situation of flooding in Shanghai, the sponge city will be constructed efficiently according to local conditions.

5. Conclusion

This paper takes Shanghai city as the research object, and analyzes the impact of rainwater flooding on Shanghai city under high intensity rainfall from the perspective of the natural environment and urban planning. And for these factors affecting waterlogging, proposed measures to solve the problem. This paper finds that the factors affecting the occurrence of waterlogging in Shanghai mainly include: the design of downspouts and drainage systems in Shanghai, the carrying capacity of the river network within Shanghai, and the topographic characteristics of Shanghai (i.e., the degree of terrain undulation). The city's drainage system was constructed early, and in recent years, the capacity of the drainage system has been significantly reduced, even hindering drainage and creating flooding points. Shanghai's river network is densely arranged, and the water surface rate of rivers and lakes is also increasing year by year, which may be able to reduce the risk of flooding. In addition to this, Shanghai's relatively undulating terrain and small surface vegetation cover can easily lead to the pooling of surface runoff, which is not conducive to natural infiltration and poses a certain risk. Measures that can be adopted to address these factors include upgrading urban greening, building smart platforms, and building sponge cities. Through these measures, increasing the greening area, increasing the utilization of water resources, and real-time monitoring of flood-prone areas can effectively mitigate the effects of waterlogging. In future research, it is recommended to analyze the risk of flooding in various parts of Shanghai through scientific methods based on the main factors of flooding with the help of artificial intelligence tools and based on a larger and more comprehensive range of data. In this way, the prevention and control of waterlogging can be adapted to local conditions, and more significant prevention and control effects can be obtained.

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