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Flood Control and Evaluation Study Based on Small Watershed Units and Urban Topography for Wuhan City

Jing Wu[1*]

[1] School of Urban Design, Wuhan University, Wuhan, China

Email Address

jing.wu@whu.edu.cn (Jing Wu)
*Correspondence: jing.wu@whu.edu.cn

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Abstract:

In recent years, urban flooding has become increasingly frequent in China's major cities. As of 2017, more than 90% of cities in China have experienced urban flooding of varying degrees. The problem of urban flooding has become an important issue constraining urban development and residents' safety. Based on this background, this paper selects Wuhan's heavy rainstorm event n on July 6, 2016, and extracts the remote sensing image data of June 5, 2016 and July 23, 2016, respectively, and calculates urban flood accumulation density (UFAD) in Wuhan. Small watershed units (SWUs) based on hydrological perspectives are selected as the basis for regional classification. Based on the correlation analysis between UFAD and the topographical factors (elevation, relief and roughness) for SWUs, this paper quantifies the impacts of the topographical factors on UFAD, and then proposes the urban flooding risk grade for all SWUs. Based on this, it proposes the disaster mitigation control evaluation based on topographical factors for SWUs in Wuhan.

Keywords:

Wuhan City, Small Watershed Unit, Disaster-Relief Terrain, Control Evaluation

1. Introduction

China's urbanization continuously deepens along with fast economic development since the 21st century. However, urban flooding events and disasters are increasingly frequent for big cities in China (Wang Weiwu et al., 2015). Between 2008 and 2016, 351 cities in China faced varying levels of urban flooding (Zhang Wei et al., 2016). A series of heavy flooding occurs in mega cities of China, including the Beijing "July 21 Incident" in 2012, the Shanghai "September 13 Incident" in 2013, the Wuhan "July 6 Incident" in 2016, and the Chongqing "June 8 Incident" in 2017.

Frequently occurring urban flooding not only affects the production and life of urban residents, but also seriously impedes the sustainable development of urban transportation, environment, health, economy and society (Fletcher et al., 2015). In fact, urban flooding has become a key issue limiting urban development (Van Rooijen et al., 2005). Therefore, studying and mitigating urban flooding has become a major issue for realizing China's new urbanization and sustainable urban development.

In order to confront the increasingly serious problem of urban flooding, the Chinese State Council and the Ministry of Housing and Urban-Rural Development successively issued the "Notice on Doing a Good Job in Constructing Urban Drainage and Heavy Rain Prevention and Control Facilities" (Guobanfa [2013] No. 23) and "The State Council's Opinions on Strengthening Urban Infrastructure Construction" in 2013. By 2014, the Ministry of Housing and Urban-Rural Development of China issued the "Technical Guide for Sponge City Construction- Constructing Rainfall System for Low Impact Development (Trial)", and it determined "Sponge City" as one of the major development strategies for China's modern urban construction, thus proposing concrete construction measures for easing urban flooding at the national level (Li et al., 2015; Che et al., 2015).

Urban flooding not only troubles China but also influences developed economies. Thus, there have been many overseas studies focusing on urban flooding. Integrated Urban Water Management (IUWM) and Sustainable Urban Water Management (SUWM) were successively proposed at the end of the 20th century (Briony et al., 1998; Susan, 1999; Azeo, 1989; Stuart et al., 2011). Then, urban water resources management was studied from a variety of perspectives including social, economic, and environmental, and new concepts were proposed to improve urban water management, including: strategic urban transformation (Ferguson et al., 2013; Sullivan et al., 2017; Brown et al., 2009), public policy formulation (Morison et al., 2011), management model optimization (Romnee et al., 2015; Floyd et al.; 2014), sustainable water environment management (Hugh Howes, 2008), balancing environmental impact and economic benefits (Torre, 1989; Sharma et al., 2016).

Overseas academic theories have been continuously introduced into China in recent years for facilitating constructing sponge cities in China. These theories include Best Management Practices (BMPs), Low Impact Development (LID), Sustainable Urban Drainage System (SUDS), Water-Sensitive Urban Design (WSUD), Green Stormwater Infrastructure (GSI), Low Impact Urban Design and Development (LIUDD) (Alexander et al., 2007; Pickett et al., 2004, 2013) (Table 1). Although these theories differ in their research scope and contexts, their core aims are similar in addressing integrated urban water issue via sustainable ecological stormwater and flood management methods (Fryd et al., 2012; Kuller et al., 2017). Therefore, objectively and accurately determining the causes and influencing factors of urban flooding is critical for current urban construction and development in China.

Table 1. *Theoretical analysis table.*

Name	Time	Country	Characteristics
Best management practices (BMPs)	1972	USA	Targeting the problem of non-point source pollution and focusing on water quality
Low impact development(LID)	1990	USA	Controlling sources of stormwater runoffs with decentralized and small-scale measures
Sustainable drainage system	1999	UK	Controlling rainwater runoff through hierarchical emissions
Green Rainwater Infrastructure	2000	USA	Multi-source control of rainwater

Water sensitive urban design (WSUD)	1994	Australia	Integrated space design and integrated water resources management at city scale
Low Impact Urban Design and Development	2000	New Zealand	Comprehensive management of watershed categories to protect the integrity of water ecosystems
Sponge City	2014	China	Effectively control rainwater runoff and use natural power to drain water

In fact, the formation of urban flooding is a complex process. Urban flooding is an urban disaster caused by many factors such as natural conditions and artificial interference (Li et al., 2017; Ma et al., 2017, 2018; Wang et al., 2017), and it is the result of the combined effects of urban topography, climatic conditions, and development intensity (Quan et al., 2010; Wu Jing, 2013; Wu Jiansheng et al., 2017). Topography is one of the most important factors influencing the formation mechanism of urban flooding (Zhang et al., 2015). The famous Chinese meteorologist Zhu Kezhen pointed out that urban flooding disasters have a close relationship with urban topography in his book "*Zhili History Geographical Environment and Flood Disasters*" (Xie Lihua et al., 2013). This relationship has been confirmed by scholars at home and abroad since the 21st century, and topography is found to play an important role in the redistribution of urban floods (Luan et al., 2017; Feng Qiang et al., 2005; Ma Guobin et al., 2012). Current urban water management lack sound understanding and prediction of natural ecological and hydrological processes (Konyha et al., 1995), and it mostly divides hydrological units according to administrative districts (Dong, 2009; Zhao Wei et al., 2014). This often results in the scale and boundary mismatch between administrative districts and natural hydrological units. A small watershed unit is a complete, relatively independent and closed natural current collection area, and it is not only the smallest unit for the collection of rainfall and runoff, but also a comprehensive unit for resource management and planning (Wu Xuepeng et al., 2009). Thus, the division of small watershed units should be closely related to urban topography and meets the basic characteristics of regional hydrology (Wang Ziwen et al., 2003). Thus, this study considers both small watershed units and urban topography and seeks to solve urban flooding according to the coupling relationship between natural hydrographic texture and urban pattern.

In summary, a series of studies have been carried out at home and abroad on the correlation of urban flooding and urban topographical elements, and rich theoretical and practical results have been obtained. Urban flooding formation is complex and influenced by many factors, and merely analyzing the influence of topography on urban stormwater runoff from heavy rain processes is insufficient for the comprehensive control and prevention of urban flood. Meanwhile, studies based on traditional administrative district divisions are unable to realistically assess the flooding risks of different urban areas. According to examination result of current available literature, there are no reported applied studies that uses hydrological small watershed units as the basis, rather than administrative districts, for dividing urban arears for studying urban flooding, and that applies disaster-reduction terrains at the city scale.

Based on the perspective of hydrological management, this paper uses small watershed units as research units, and proposes a terrain control strategy for urban flooding mitigation and relief. It further enriches the depth of research in this field and has certain practical implications. It can effectively help government departments to respond more effectively and effectively to urban flooding, and to provide orderly protection, development and construction of cities, and to improve urban flooding governance and overall development.

2. Study Area

2.1. Study Area

Wuhan City is selected as the research area for this study. Wuhan is the central city in central China and it is located at East Longitude 113º41’ to 115º05’ and North Latitude 29º58’ to 31º22’. Its total area is 8561.15 square kilometers, and its main urban area is 863 square kilometers. (Figure 1) Wuhan City is in the middle and lower reaches of the Yangtze River, and with rich patterns of rivers and lakes, and dense water networks, it enjoys the reputation of “city of hundreds of lakes”. There are 27 lakes in its main urban area, and the total water area accounts for about 25% of its total land area. It is in the subtropical humid monsoon climate zone. Heavy rains mainly occur from May to September. The rainfall during this period accounts for 35%-45% of the total annual rainfall. Its topography is dominated by the undulating landform between hills and plains. The surface of its main urban area is below the flood level all year round. Under the regional rainstorm conditions, Wuhan City is highly prone to urban flooding disasters.

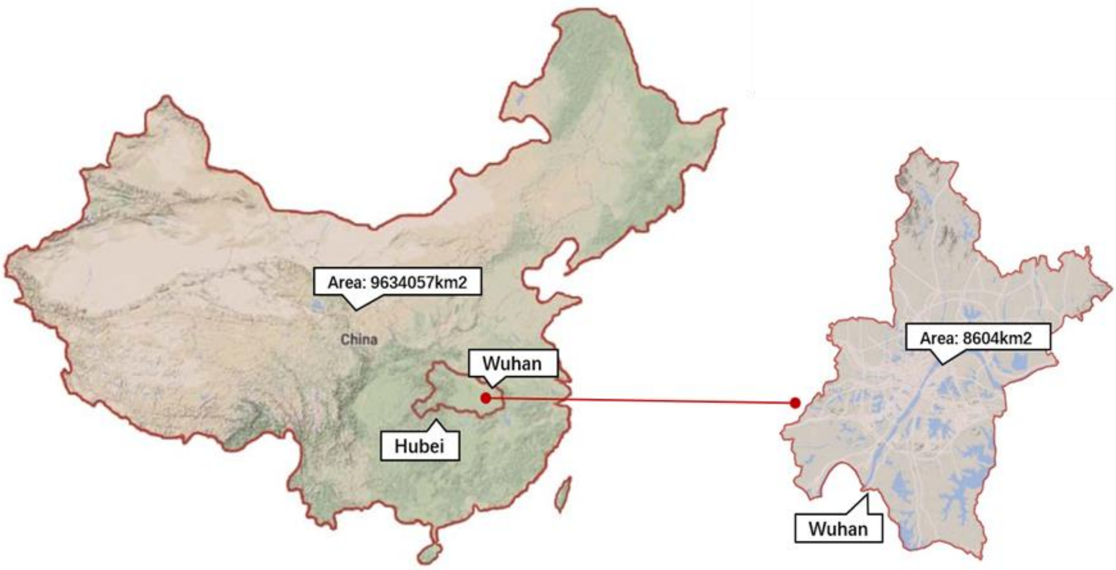

Figure 1. *Location map of Hubei Province and Wuhan City.*

2.2. Wuhan’s Urban Flood Situation

Wuhan City has experienced frequent flooding events in recent years due to its special topography, geomorphology and climatic conditions. The most typical is the extraordinary heavy rain event on 6 July 2016. During the week from June 30 to July 6, the precipitation in Wuhan’s main urban area reached 580mm, and the precipitation reached 44% of the annual average precipitation. This resulted in urban flooding for large urban areas. In the main urban areas, there were more than 200 places of waterlogging, and the airport highway collapsed. Even when the stormy weather was gone and it turned sunny, some communities were in flooding for up to one week. As of July 6, this heavy rain incident caused economic losses of 2.265 billion yuan, the death of 14 people and one missing. Sudden urban flooding leads to the disruption of urban traffic, damage to public facilities, flooding of houses and various secondary disasters and social problems. It not only causes severe impacts on urban production and life, but also impedes the sustainable development of the economy, environment and society. Thus, it became a current important issue plaguing urban construction. Because of Wuhan’s propensity to urban flooding, the National Flood-Control General Office of China listed it as member of the 31 key flood-control cities in China in 2013 (Figure 2). Wuhan City was included in the first-batch of pilot cities in China's sponge city program in 2015 (Figure 3). This justifies why this paper selects Wuhan City as the research case of urban flooding.

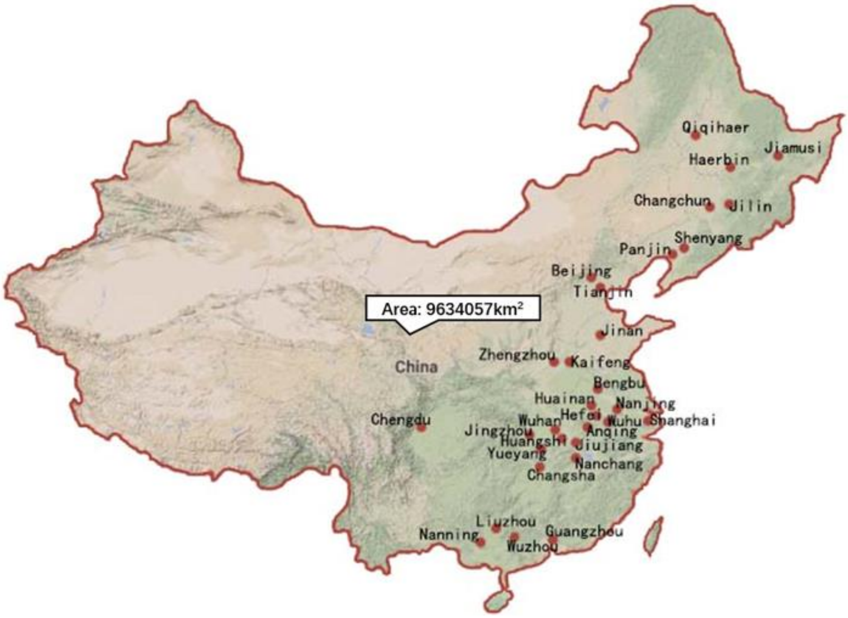

Figure2. *Distribution map of China's 31 key flood-control cities.*

Figure3. *Distribution map of China's first batch of pilot sponge cities.*

3. Materials and Methods

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3.1. Data Selection and Processin

This study was based on the heavy rainstorm event on July 6, 2016. Based on Landsat 8 OLI_TIRS satellite data, ArcGIS was used to extract the two groups of remote sensing image data for the on July 23, 2016 (after the storm). Geometric correction and edge-enhanced image processing boundaries of Wuhan's urban flood accumulation areas on June 5, 2016 (before the storm) and were applied to the boundaries, and then the two groups of data were superimposed to generate the distribution map of urban flood accumulation areas within Wuhan City (Figure 4). The Digital Elevation color bands to be displayed were adjusted by attribute settings to extract the surface elevation, slope, and roughness distribution maps of Wuhan (Figure 5, Figure 6, Figure 7). Model (DEM) elevation data of 30-meter accuracy was loaded in ArcGIS 10.5.

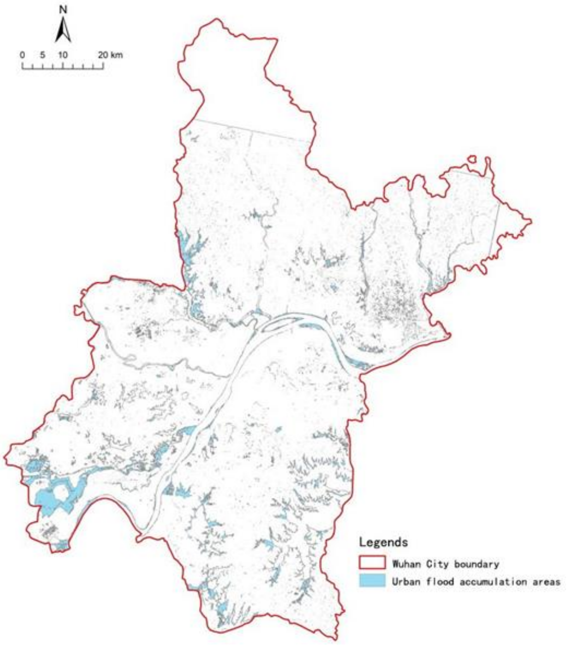

Figure 4. *Distribution map of urban flood accumulation areas within Wuhan City.*

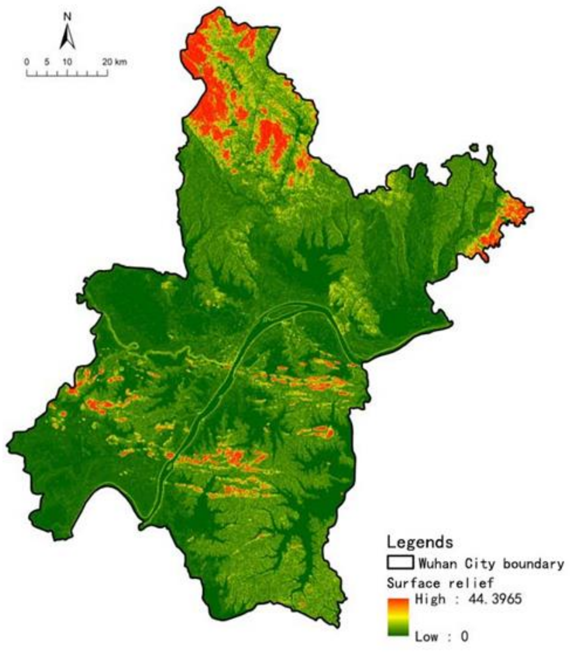

Figure 5. Analytical diagram of Wuhan's surface elevation.

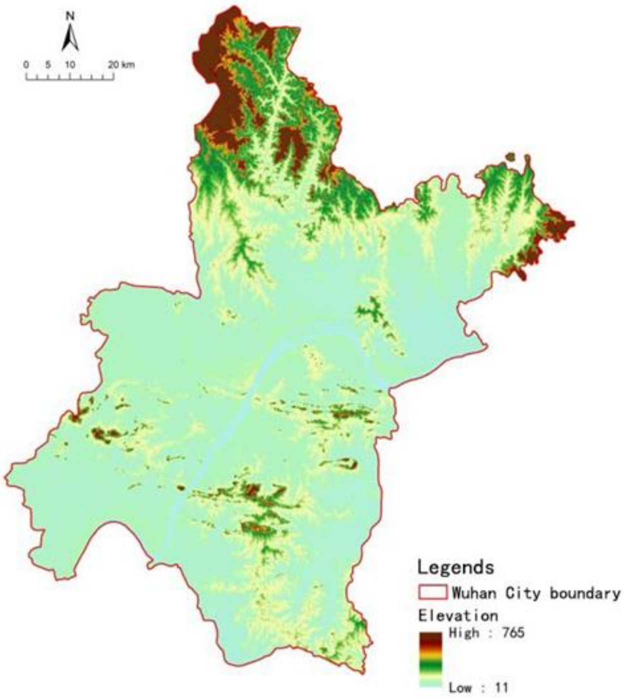

Figure 6. Analytical diagram of Wuhan's surface relief.

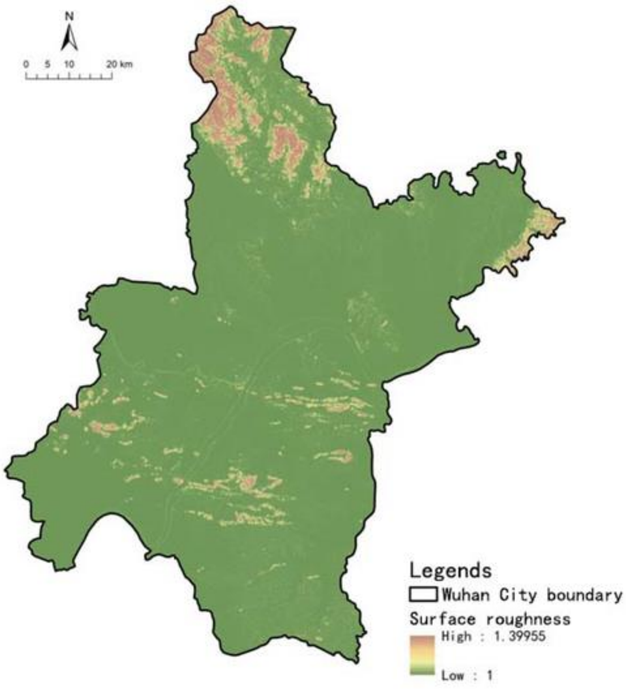

Figure 7. Analytical diagram of Wuhan's surface roughness.

3.2. Extraction and Delineation of Small Watershed Units

In ArcMap 10.5, the DEM elevation data of 30-meter accuracy is loaded, and the original DEM data is filled using Spatial Analyst Tools—Hydrology—Fill to obtain a sink-free DEM. The D8 algorithm was applied to calculate and measure the direction of water flow in ArcGIS; for each grid, its elevation is compared with those of its surrounding 8 grids to obtain the direction of the water flow, and finally a grid map was obtained. In order to ensure the extraction accuracy of the small watershed units in the study area, a 30m*30m grid was adopted to capture surface water flow path, water systems network classification, basin boundary, and catchment units. Then, small watershed units were measured and used as basic research units.

The hydrological analysis function of ArcGIS software was applied for river network extraction and for calculating the area of accumulated water. Sinks and spikes in the topography were applied with cell processing to calculate the water accumulation/water flow direction, and the watersheds were automatically divided according to the size of the designated drainage area. The small watershed units were extracted by simulating the direction of water flow, river basin confluence, the automatic generation of water networks, the determination of watershed outlets, and the boundaries of sub-watersheds. When extracting small watershed units in Wuhan, small watersheds surrounding Wuhan City and with area of less than 10km2 were merged into the largest adjacent watersheds. Thus, 84 small watershed units in Wuhan were finally designated and delineated, and their partitioning coding and eigenvalue calculations were carried out. (As shown in Figure 8)

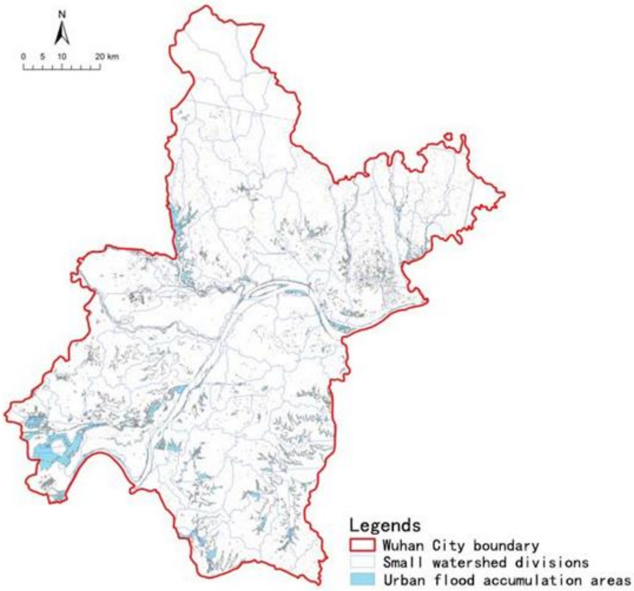

Figure 8. *Spanning graph of Wuhan's small watershed divisions.*

3.3. Defining he Research Object

Arc GIS was used to superimpose the distribution map of urban flood accumulation areas within Wuhan City and Wuhan's small watershed partitioning map, and to generate correlational analysis diagram of Wuhan's small watershed divisions and its urban flood accumulation areas (Figure 9). Small watershed units were used as the calculation unit to calculate the urban flood accumulation area and density for each unit. Based on this, GIS was used to measure the DEM topographic data, and this generated data of three topographic elements (average surface elevation, average surface relief, and average surface roughness) for all small watershed units of Wuhan City.

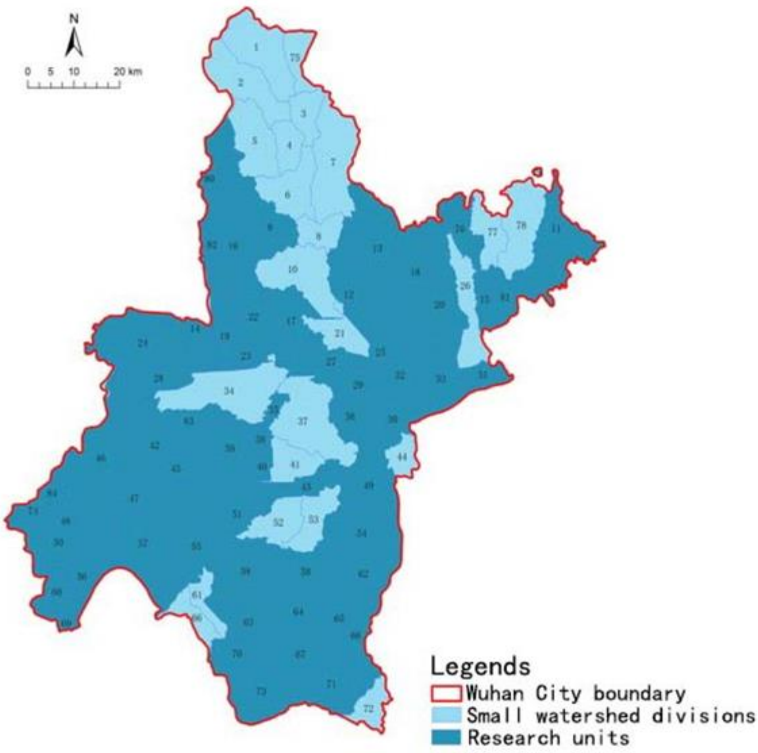

Figure 9. *Numbering diagram of Wuhan's small watershed divisions.*

Based on the designated 84 SWUs, the size of urban flood accumulation area in each SWU was measured, and this study extracted 60 SWUs that were bigger than ≥ 1% of the total flood accumulation area. (Figure 9) It selected the typical 60 SWUs with significant characteristics as the research objects.

4. Results and Analysis

4.1. Correlation Analysis

For the obtained 60 SWUs with typical flooding characteristics, correlation analysis was carried out between Wuhan's urban flood accumulation density (UFAD) and the three average topographical factors (surface elevation, surface relief and surface roughness). This generated the SWUs that are most correlated with UFAD.

4.1.1. Correlation Analysis of UFAD and Average Surface Elevation

According to the correlation analysis of UFAD and Average Surface Elevation (Figure 10), the two have higher correlation when the elevation ranges from 20-40m and UFAD is 0.041-0.088. This shows that Wuhan's urban flooding mainly occurs within the range of 20-40m average surface elevation.

According to the above statistical results, the average surface elevations were divided into three categories: 20-30m, 30-40m and >40m. The quantities of SWUs were calculated for each category. The results show that the 20-40m category has 35 SWUs with average UFAD of 0.088, accounting for 58% of the total number of SWUs. (Table 2) There are only 5 SWUs in the >40m category, and their average UFAD is 0.041, accounting for only 8% of the total SWUs. This demonstrates that the higher the average surface elevation, the lower risks of urban flooding for SWUs.

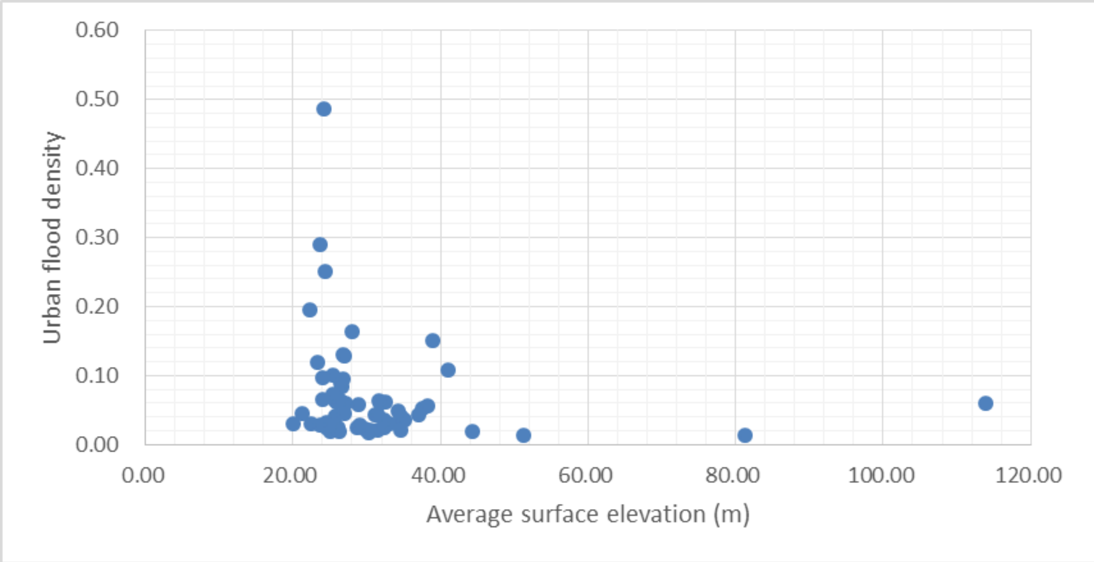

Figure 10. *Analytical diagram of Wuhan's average surface elevation and its urban flood density.*

Table2. *Analytical diagram of Small Watershed Units under the influences of UFAD and surface elevation.*

Average surface elevation (m)	Number of small watershed units	Average flood density
20-30	35	0.088
30-40	20	0.044
＞40	5	0.041

4.1.2. Correlation analysis of UFAD and Average Surface Relief

According to the correlation analysis result via SPSS, the higher correlation between UFAD and Average Surface Relief is mainly concentrated at the Average Surface Relief of 0-1 °, and the UFAD of 0.042-0.089. This shows that urban flooding in Wuhan mainly occurs within 1 °of average surface fluctuation, namely within less undulating area.

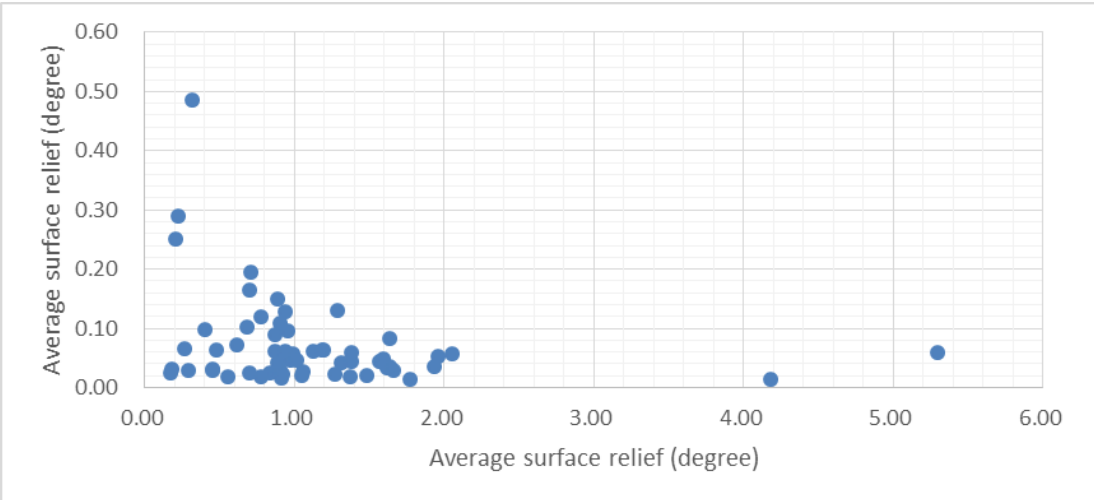

Figure 11. *Analytical diagram of Wuhan's average surface relief and its urban flood density.*

According to the above statistics, the average surface reliefs were divided into three categories: 0-1°, 1-2°and >2°. The quantities of SWUs under different UFAD were calculated for each category. The results show that there are a total of 34 SWUs in the 0-1°category, and their UFAD is 0.089, accounting for 58% of all SWUs. (Table 3) SWUs in the 1-2°category account for 37% of all SWUs. Moreover, only 3 SWUs are in the > 2°category, and their UFAD is 0.042, accounting for only 5% of all SWUs. This demonstrates that the higher the average surface relief, the lower risk of urban flooding for SWUs.

Table3. *Analytical diagram of Small Watershed Units under the influences of UFAD and surface relief.*

Average surface relief (°)	Number of small watershed units	Average flood density
0-1	34	0.089
1-2	23	0.044
> 2	3	0.042

4.1.3. Correlation Analysis of UFAD and Average Surface Roughness

After calculating the correlation statistics of UFAD and Average Surface Roughness, it is found that higher correlation between the two takes place in case of Average Surface Roughness of 1.000°-1.002° and UFAD of 0.034-0.076. This shows that urban flooding in Wuhan mainly occurs in low-roughness areas.

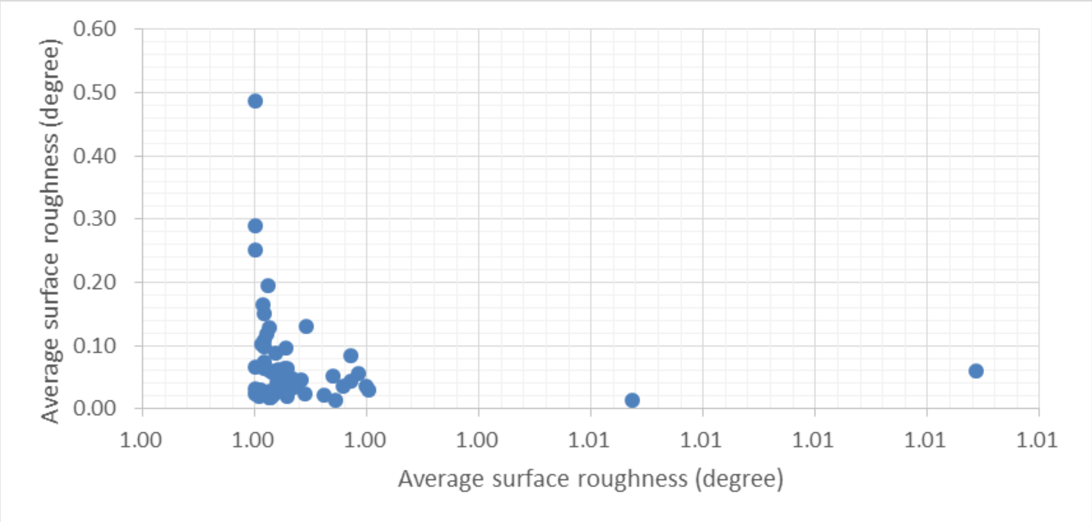

Figure 12. *Analytical diagram of Wuhan's average surface roughness and its urban flood density.*

Via the scatter plot analysis of UFAD and Average Surface Roughness, the average surface roughness data are divided into three categories: 1.000°-1.001°, 1.001-1.002°, and >1.002°. The quantities of SWUs are calculated for each type. The statistical results show that low-roughness SWUs have higher risks of urban flooding, namely higher UFAD. The 1.000°-1.001° category has 49 SWUs, and their UFAD is 0.076, accounting for 81% of all SWUs. (Table 4) Thus, the higher the average surface roughness, the lower risks of urban flooding for SWUs.

Table4. *Analytical diagram of Small Watershed Units under the influences of UFAD and surface roughness.*

Average surface roughness (°)	Number of small watershed units	Average flood density
1.000-1.001	49	0.076
1.001-1.002	7	0.042
> 1.002	4	0.034

In summary, via correlation analysis between UFAD and three topographical factors (elevation, relief and roughness), it is found that Wuhan's urban flooding (measured by UFAD) has close correlation with the three factors. In short, the lower the elevation, the smaller the relief, the lower the roughness, the higher risks of urban flooding.

4.2. Impact Analysis

According to the three sets of correlation analysis results above, SWUs having highest correlation with the three types of topographical factors are classified by flooding risk as below:

Type A: The 35 SWUs with average surface elevation of 20-30m are designated as Risk SWU A.

Type B: The 34 SWUs with average surface relief of 0-1 are designated as Risk SWU B.

Type C: The 49 SWUs with average surface roughness of 1.000-1.001 are designated as Risk SWU C.

The above three types of SWUs were separately subjected to three-type superposition, two-type superposition and single-type analysis so as to quantify the degree of correlation of high-risk SWUs with three variables, namely elevation, relief and roughness. According to Table 5, among the three-type superimposed data, 29 SWUs have the highest flooding risks, accounting for 48% of the SWUs.

Table 5. *Classification table for the impacts of topographic factors on SWUs.*

Superimposition category	Name of superimposed small watershed units	Number of small watershed units	Numbering of small watershed units
three-type	ABC	29	14,15,17,19,20,23,24,27,28,29,31,33，38,39,40,43,48,50,54,56,57,60,62,65,68,69,70,73,74
two-type	AB	0	
	BC	5	12,16,22,45,82
	AC	5	35,36,55,83,84
single-type	A	1	30
	B	0	
	C	10	13,18,25,32,63,64,67,71,76,81

Among the two-type superposition data, each of BC superposition group and AC superposition group has 5 SWUs, each accounting for 8% of the total number, but the significance is not strong. However, among the two sets of data, all SWUs have Type

C roughness, accounting for 100% of the total SWUs, indicating high significance. In the single-category data, there are only 1 Type A SWU, 0 Type B SWU, and 10 Type C SWUs, accounting for 16% of all SWU, accounting for 90% of single-type risk SWU, with high significance. Through the above analysis, it can be found that among the three types of topographical variables, Type C surface roughness has the highest impact on SWUs and the flooding risks are highest. Surface relief has the least impact on urban flooding in Wuhan, and relevant risks are low.

On this basis, UFAD is classified into three types, namely > 0.1, 0.05-0.1, and <0.05, and then descriptive statistics were carried out for superimposed data. (Table 6) The results show that there were 11 SWUs in the > 0.1 type, accounting for 73% of ABC superimposed SWUs, and they have high risks.

The number of SWUs meeting one type of topographical element and having UFAD bigger than 0.1 is 0. This indicates the one type of topographical element does not have a typical effect on the production of urban flooding.

There are 17 SWUs having UFAD between 0.05 and 0.1, which account for 28% of all SWUs, and account for 53% of ABC superimposed SWUs, and they have relatively high risks. A total of 53% SWUs have UFAD lower than 0.05, indicating that more than half of all SWUs are at low risk level for urban flooding.

Table 6. *Classification table for High-risk SWUs.*

Urban flood density	Number of small watershed units	Small Watershed Unit Numbering	Percentage		
			three-type	two-type	single-type
> 0.1	11	15,16, 19,27, 50,55, 56, 60, 69,73, 82,	0.73	0.27	0
0.1-0.05	17	14,23,30,48,54,57,58,59,62,63, 67,68, 70,74,80,81,83	0.53	0.06	0.24
< 0.05	32	9,11,12,13,17,18,20,22,24,25,28,29,31,32,33,35,36,38,39,40,42,43,45,46,47, 49,51,64,65,71,76,84	0.38	0.19	0.22

According to the table 5 and table 6, 29 SWUs covered by ABC superimposition are taken as the highest risk sub units. The flooding risks of SWUs are evaluated according to their UFAD, and rated at different grades as below. Wuhan City's urban flooding risk grade classification map is given as below. (Figure 13)

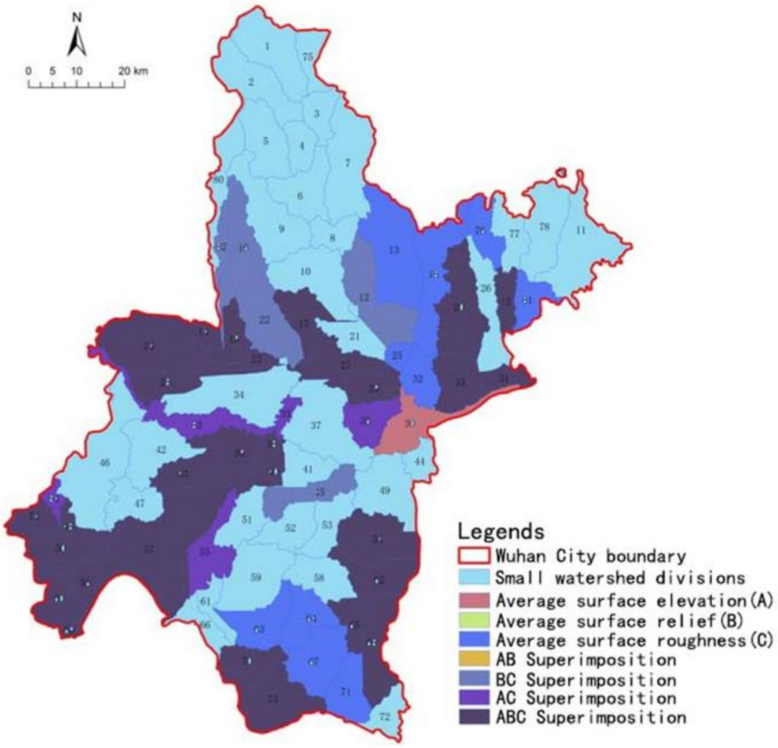

Figure 13. *Superimposition analysis diagram of Wuhan's small watershed units.*

4.3. Evaluation for Disaster Mitigation and Control

Based on the urban flooding risk grade map for SWUs, this paper considers the real conditions of corresponding sites of SWUs, and regards terrain conditions as an important base for urban flooding formation. (Figure 14) It proposes a SWU-based flooding-control evaluation system. Currently, most SWUs with high flooding risk are built-up urban areas, this study proposes relevant SWU-based r regulatory evaluation from the perspectives of optimization and control.

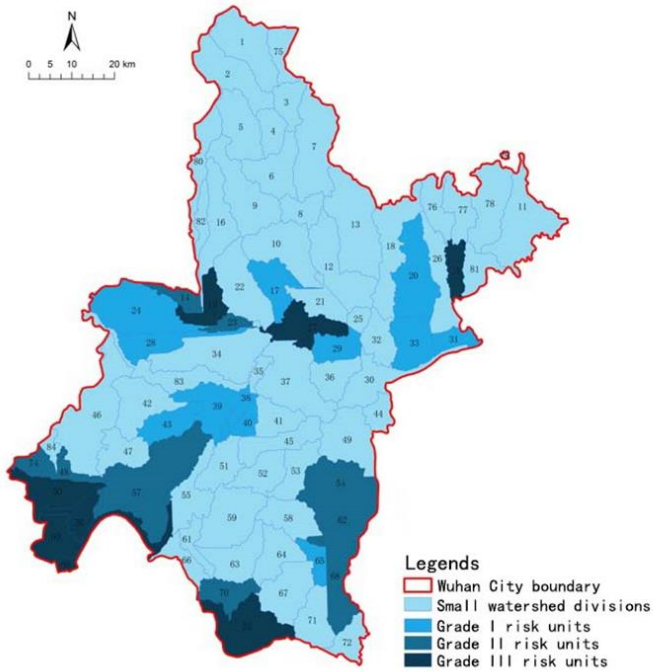

Figure 14. *Distribution map of the risk grades of Wuhan's small watershed units.*

4.3.1. Grade I Risk Unit

There are altogether 8 SWUs that meet three terrain influencing factors, and have UFAD bigger than 0.1, and they are numbered as 15, 19, 27, 50, 56, 60, 69, and 73. This study regards the 8 SWUs as Grade I Risk Unit, and they are highest risk area of urban flooding. Superimposing the Grade I Risk Unit map with Wuhan's aerial photograph, this paper finds that all these highest risk areas are around the Yangtze River and Wuhan's various lakes. Their land use types are farmland, fish ponds and roads, and there are few construction sites. Most of their administrative areas are located outside Wuhan's Third-Ring Road, and they are stilling waiting for development. This also reflects, to some extent, the importance of natural elements in the urban flooding risk units of Wuhan City. These high-risk SWUs have high possibility of future regulation.

Based on the above analysis, the regulatory strategies proposed for Grade I SWUs are:

1) Increasing the river-side and lake-side elevations and relief based on the sink flow and convergence directions of SWUs, and suggesting elevation risk control areas and control lines;

2) Increase surface roughness, set risk control lines for existing farmland, fish ponds and roads, increase green capacity units appropriately, and set green volume ratios and quality control ratios for different risk units to increase the water-regulating capacity of farmland and fish ponds.

3) Improve the connectivity of these SWUs with surrounding Yangtze River and lakes, optimize the water system layout by de-meshing, and build the natural network based on the protection of natural terrain, so as to establish a water network where lakes and rivers are well connected.

4.3.2. Grade II Risk Unit

There are 9 SWUs satisfying the three terrain influencing factors and having UFAD bigger than 0.05, and they are numbered as 14,23,48,54,57,62,68,70,74. This study regards them as Grade II Risk Unit, and they are middle risk areas of urban flooding.

Among them, 4 SWUs are closely related to the Yangtze River and lakes in Wuhan. Compared with Grade I Risk Units, their connections with water systems are significantly reduced. At the same time, the 9 SWUs are all concentrated outside The Third-Ring Road, but they are much closer to the city center than Grade I Risk Units. Their land use type is still similar to those of Grade I Risk Units, mainly farmland, fish ponds and roads. However, the proportion of construction land is significantly higher than that of Grade I Risk Units.

Based on the above analysis, the regulatory strategies proposed for Grade II Risk Units are presented as below:

1) Incrementally increase the flood control line and the relief control area according to the direction of the convergence line;

2) Increase the green volume of the marginal area of the construction area within the built-up area. With the premise of increasing surface roughness, propose a SWU-based risk control line for construction land;

3) Optimize the rationing relationship between farmland, fish ponds and roads, and

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improve the connectivity between SWUs and the surrounding Yangtze River and lakes according to convergence conditions, propose an SWU-based water storage optimization control line for farmland, fish ponds and roads.

4.3.3. Grade III Risk Unit

12 SWUs satisfies the three topographical influence factors and have an UFAD lower than 0.05, and they are numbered as 17,20,24,28,29,31,33,38,39,40,43,65. These 12 SWUs are defined as Grade III Risk Units, and they are low-risk area of urban flooding.

They account for 41% of the total number of SWUs, and they have the largest share among the three types of risk units. Among them, 7 SWUs are bordered by the Third Ring Road, 4 SWUs are within the Third Ring Road and only 1 is outside the Third Ring Road. Compared with the above two types of risk units, Grade III Risk Units presents a close coupling relationship with the main urban areas. At the same time, their types of land use are also dominated by road traffic, residential areas, supplemented by farmland, fish ponds, and industry.

Based on the above analysis, the regulatory strategies proposed for Grade III Risk Units include:

1) Based on convergence conditions, pay close attention to the degree of integration with the urban center area, and propose a flooding-risk elevation control line and relief control area;

2) Based on the premise of increasing surface roughness, propose proper grades for SWU-based green volume proportions for farmland, fish ponds and industrial zones;

3) Based on the velocity flow and direction and convergence unit, for the hard built areas such as roads and residential areas, propose flood-control construction-forbidding and control area.

To sum up, in the research of control evaluation, this study proposes corresponding specific control evaluations according to SWUs of varying degree of flooding risks, and constructs the overall terrain control evaluation from both optimization and control. At the same time, according to the site characteristics of SWUs of varying grades of flooding risks, this study proposes a risk control evaluation that simultaneously adapts to the flooding risk grade and corresponding site characteristics. This is intended to achieve ultimate combination of SWUs and urban construction management and to achieve effective flood prevention and disaster reduction. Therefore, this study provides strong data basis for disaster reduction and construction in Wuhan City in the future, and provides planning support for effectively improving and alleviating the occurrence of urban flood problems.

5. Discussion and conclusion

5.1. Conclusion

(1) This study studies the correlation and influence of urban topography and urban flooding. The lower the site elevation, the smaller the site relief, and the lower the site roughness, the more likely the site is to experience urban flooding. Surface roughness is the topographical influence factor that has the greatest impact on urban flooding.

(2) This study combines urban flooding density and high risk SWUs in Wuhan City

to classify the flooding risks of different sites of Wuhan City. Based on this, combined with the city's backgrounds and conditions, this study proposes a targeted and operable flooding-control evaluation flooding within Wuhan. The results of this study have practical significance for the future development and construction of Wuhan City, and provide a concrete solution to the mitigation of flooding problems in Wuhan.

5.2. Discussions

This study still has some limitations.

(1) The data within one week after the storm event was unable to extract due to poor image quality in the study area because of cloud cover. Therefore, this study extracts remote sensing data that can be extracted before and after the heavy storm. Since this data does not cover the most serious period of urban flood accumulation in the heavy rain event in Wuhan, the findings of this study do not represent the results of the most serious rainstorm period in Wuhan. In addition, using a rainstorm event as a source of research data does not have universal applicability and further studies could be carried out via basing on multiple storm events in future.

(2) Urban flooding is a disaster caused by many natural and human factors. This study explores effective strategies to alleviate urban flooding merely from the perspective of topography. Its research results have certain limitations.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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