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Research Paper

Developing concept on sponge city arrangement for flood hazard mitigation: A case study of Wuhan, China

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ABSTRACT

As a frequently flooded city, Wuhan is one of the key cities that need to improve the abilities against flooding hazards. The recent rainstorms happened in Wuhan led to floods and threatened people's lives as well as made huge economic losses so that it is urgent to develop an overall Sponge City System in Wuhan. This paper investigates the reasons that Wuhan frequently suffered from severe flooding hazards, including (1) flat topography, (2) heavy precipitation, (3) reduction of lake area, (4) decreased capacity of drainage system. By consideration of these conditions in Wuhan, specific methods based on Sponge City are recommended. According to overall consideration of waterlogging risk, flooding impacts and Sponge City effects, key regions that need to be given priority to develop Sponge City are proposed. Then, this paper proposes following Sponge City arrangement: (1) recovery of water ecosystem and water quality status in Wuhan is recommended. (2) Based on the existing gardens in urban area, adjustments of bio-retention or rain gardens including increasing the proportion of rain gardens in residential regions and along lakes are proposed. (3) GIS is used to analyze the topography, build rain flood model based on DEM and monitor the waterlogging in order to reduce flooding hazards and improve the ecological environment in Wuhan. By analysis and constructions of Sponge City in Wuhan, the harmful effects of flooding will be reduced and the ecological environment will be improved.

1. Introduction

With the rapid urbanization process, natural conditions changed a lot and led to a series of hazards related to human activities. The flooding hazard and water pollution (Du et al., 2014, 2015; 2016) are often considered as consequences of urbanization. Under the traditional development practices, the urbanization has resulted in increased surface runoff (Hollis, 1977; Jennings and Jarnagin, 2002; Dietz, 2007), increased runoff velocity (Dietz, 2007), increased stormwater runoff volumes and peak flows (Damodaram et al., 2010), decreased water quality (Makepeace et al., 1995; Dietz, 2007). Best Management Practices (BMPs) were designed to mitigate the negative effects of flood, but they didn't mitigate other hydrologic impacts such as

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inadequate base flow and flashy hydrology (Damodaram et al., 2010). To mitigate the negative effects of urbanization, Low Impact Development Practices (LID) were proposed in America (Dietz, 2007) and is widely promoted to control runoff, reduced peak discharge, prevent floods and improve the water quality (Hood et al., 2007). Then, there are so many development practices to improve the ecology of water, Water Sustainable Urban Design (WSUD), Sustainable Drainage Systems (SuDS), Low Impact Urban Design and Development (LIUDD) and Sponge City are proposed and widely developed and used to control flood and change the traditional practices. In China, Sponge City were widely investigated since 2011 and in order to further develop Sponge City, Chinese government has planed the pilot cities to propel Sponge City. As a main city in middle of China with abundant precipitation, Wuhan has chosen as a pilot city to process Sponge City. This paper aimed to introduce the general topographic setting, climate, water resources and drainage system of Wuhan. Based on the above conditions, this paper divided ranks to every region and mark priority to key regions. This paper also provided some methods based on Sponge City. By overall plan on the Sponge City in Wuhan, it will reduce the harmful effects of floods and improve the ecological environment with low impact development.

2. Flooding hazards and waterlogging reasons

2.1 Geographic position and climate condition

Wuhan is located in the middle of China and is the capital of Hubei Province (**Fig.1**). The topography of Wuhan is low, flat and the average elevation of urban area of Wuhan is from 20 to 26m. The elevation of most fields of Yangtze River Valley is higher than Wuhan as shown in **Fig.2**. The low and flat topography makes Wuhan easily flooding.

Wuhan is a humid subtropical monsoon climate city with a large precipitation in summer months. The average annual precipitation was 1255.28 from 1962 to 2015 and in Meiyu period, the precipitation account for near 50%. Due to the large precipitation in summer, flood hazards have affected Wuhan seriously and frequently for years and lead to huge loss.

2.2 Water resources of Wuhan

With hundreds of rivers and lakes, Wuhan has the most abundant water resources in China. The total surface area of water (**Fig.3**) is 2117.6 km^3 which is 25% of territorial area of Wuhan. In 2015, Surface water resources in Wuhan was 5447 million m3, converted into runoff depth was 641.3 mm which was 52% more than 2014. (WWRB, 2016). With the process of urbanization, reduction of lake area is becoming a severe phenomenon and decrease the capacity of natural storage function. The total area of lakes in Wuhan was 983.29 km^2 in 1973 however this area was found to be 647.47 km^2 in 2013 (Chen et al., 2015). This reduction of lakes area makes flooding happening frequently.

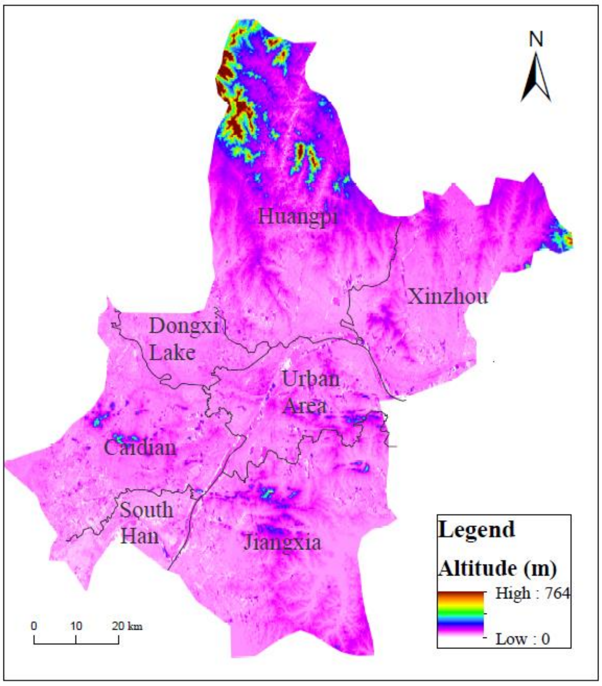

Fig. 1. Districts and topography of Wuhan

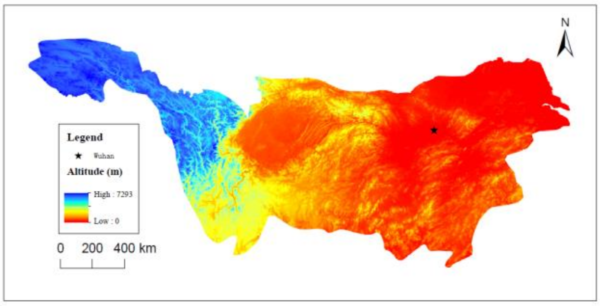

Fig. 2. Topography of Yangtze River Basin

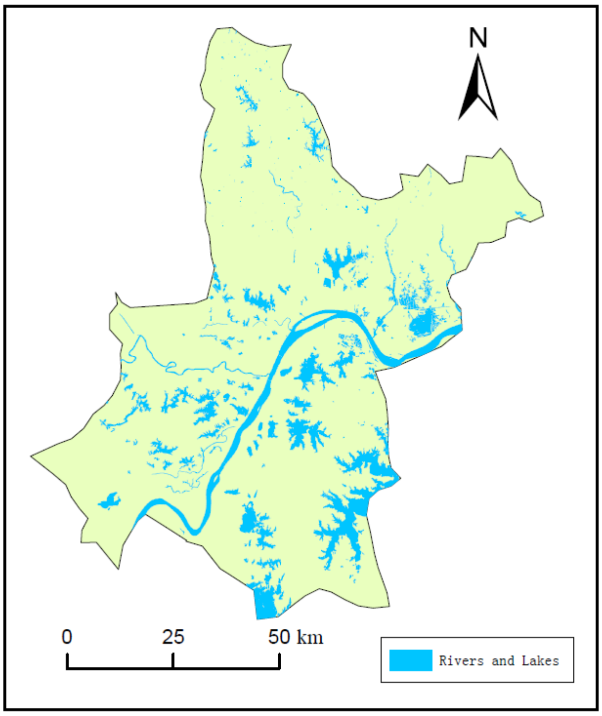

Fig. 3. Rivers and Lakes distribution in Wuhan

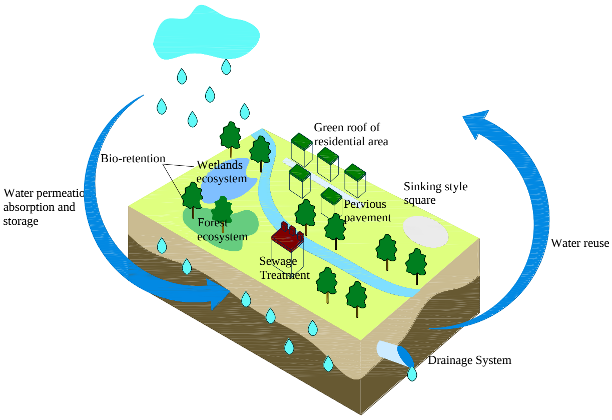

Fig. 4. Sponge City sketch map

2.3 Drainage system of Wuhan

Drainage systems in Wuhan were referred to Soviet model in 1950s. Until now, most drainage systems in Wuhan are still using the Soviet model that is adopted mixture of rainwater and sewage model. There are twenty-two drainage systems in Wuhan. Hankou, Hanyang and Wuchang mainly adopted Soviet model. Only a few regions such as Qingshan were used rain and sewage division model which is conducive to water resources protection (Zou et al., 2014). The defects of Soviet model are low rate of conduit coverage, inefficiency and low rate of sewage treated which will lead to water pollution. In Wuhan, most of the drainages are used small diameter pipes to conduit rain water. The diameter of the pipes is not matched to the rainstorm intensity and due to the limit diameter, it's easy to block and reduce the ability of drain rain water.

3. Sponge City proposal of Wuhan

3.1 Concept of Sponge City

Fast growing cities are suffering with intensified hydroclimatic hazards, so Sponge City is proposed to transform cities to sponge eco-cities to enhance the capacity on flood prevention, water resources replenishment, heat-island mitigation, water quality improvement and biodiversity development (Liu et al., 2015). The term “Sponge City” was used to describe that urban cities can absorb rain water just like a sponge and rain water can recycle to be used again. Sponge City represents a city with pervious pavements, bio-retention, green roof and natural ecological systems such as wetlands ecosystem and forest ecosystem. The water transit cycle in Sponge City will be achieved by permeation, absorption, storage, water cleaning and reuse. **Fig. 4** shows the sketch map of Sponge City used in sponge eco-cities.

3.2 Key developing area

Due to Sponge City is a long-term construction and need to be constantly put money into it, so area selection is important. Based on the priority level, government can give priority to some areas that are emergent to develop Sponge City. To divide the priority level, average precipitation, waterlogging risk, economic development level and population density are need to be considered overall. In this paper, 3 indexes are introduced to access the necessary of Sponge City development, waterlogging risk, flooding severity and vulnerability and Sponge City effects. First, waterlogging risk need to consider the precipitation and waterlogging probability. High probability of precipitation and waterlogging area will be high waterlogging risk area. Second, large scale land use types, population density and flooding related economic loss need to be considered in flooding severity and vulnerability. Third, the complexity, applicability and effects of Sponge City measures as well as the existing capacity of permeable and retention facilities are used to judge the Sponge City effects. Exiting drainage system, water ecosystem and gardens are still need to be took into account. General consideration of these 3 indexes, we can get the key developing area to determine the priority. Dependent on these 3 indexes, urban area of Wuhan is the area that need to be given priority to develop Sponge City. Firstly, urban area is belonging to high waterlogging risk area; secondly, urban area has high population density and large economic loss; Thirdly, Sponge City measures can improve the current flooding situation of urban area. **Fig.5** shows the urban area in Wuhan.

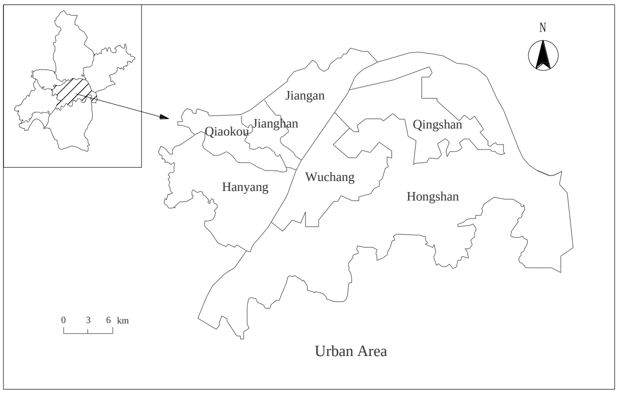

Fig. 5. Urban area of Wuhan

3.3 Arrangement of Sponge City

Because of the abundant water resources in Wuhan, Sponge policy needs to focus on establishing water ecosystem and recover of the function of water resources, assisted with permeable and retention facilities.

3.3.1 Recovery of water ecosystem

Due to there are abundant water resource such as rivers and lakes, recovery of water ecosystem and make good use of the functions of it is important and efficient. With the development of urban expansion and population growth, water pollution is severe. According to the standard of surface water environment quality(GHZBI), there are five levels for water quality from the best Ⅰ to the worst Ⅴ. For the water quality of 11 main rivers in Wuhan in 2015, there were 5 rivers passed Ⅱ which accounted for 45.4%. There were 3 rivers did not pass Ⅲ which accounted for 27.3%. For 108 water resources in Wuhan, the compliance rate with the water quality was 48.1% in 2015 (WWSB, 2016). Some rivers even did not pass the worst Ⅴ such as some regions in Yangtze River, Fu River, Xunsi River. Eutrophication is a common phenomenon for lakes in urban area and agricultural area. In 80 main lakes, only 2 lakes achieved Ⅱ, 11 lakes achieved Ⅲ and 37 lakes did not achieve Ⅳ which accounted for 46.2% in 2015 (WWSB, 2016). **Fig.6** and **Fig. 7** show the water quality and eutrophication of lakes in different administrative districts. As shown in **Fig.6**, urban area, the water quality in Jiangxia and Xinzhou were severe and more than 50% of lakes were worse than Ⅳ. **Fig.7** shows that lake eutrophication in all districts was severe and more than 50% lakes were middle eutrophication and severe eutrophication. These shows that lake water quality need to be improved to recover the functions of water ecosystem.

For the groundwater quality in Wuhan, the quality was severe as well. There are three types of the groundwater, Quatenary Holocene pore confined water, Quatenary Pleistocene series pore confined water and Carbonate fissure karst water. More than 70% of Quatenary Holocene pore confined water was evaluated as the worst (WWRB, 2016).

Due to the severe pollution in water resources and reduction of lake area, the recovery of water ecosystem needs to pay attention to the restraint the water pollution

Fig. 6. Water quality level of lakes in Wuhan

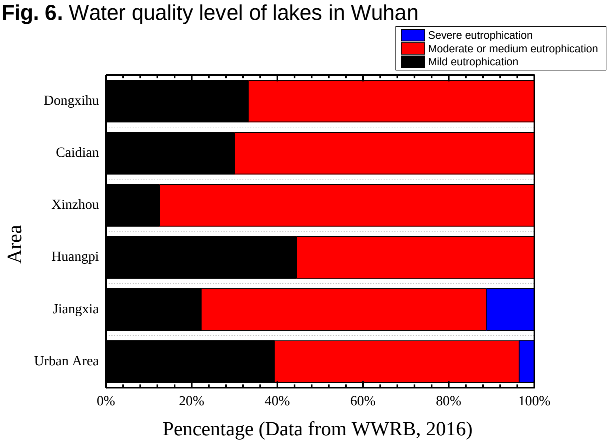

Fig. 7. Lake eutrophication in Wuhan

and lake protection. It's important to establish strict water resource management measures and related policies.

3.3.2 Bioretention

Bioretention, or variation such as bioinfiltration and rain gardens, has become one of the most available storm management methods in urbanized watersheds and these facilities substantially reduce runoff volumes, peak flows (Davis et al., 2009) and increase groundwater recharge (Dietz, 2007). Bioretention can be used in residential and commercial settings and the parameters of bioretention are media, sizing calculations and ponding time (Dietz, 2007). General features of a bioretention system include porous media, supporting a vegetative layer, with a surface layer of hardwood mulch (Hsieh and Davis, 2006).

Based on the existing gardens in Wuhan, some adjustments and bioretention methods can be developed. There are 49 gardens in urban area and 22 gardens have ecological function. From the statistics, about 70% of the gardens are cantonal and regional gardens and only 2% are community gardens. Residential regions have high-density buildings and there is a large area of impervious surface. To improve the anti-flood capacity of residential regions, regional gardens and pervious pavement are proposed. For the distribution of the gardens, a large proportion of gardens were built by along the Yangtze River and Han River and only small proportion were built along the lakes. It's important and efficient to build bioretention area or rain gardens along the lakes to adjust measures to local conditions and take full advantage of abundant lakes resources.

3.3.3 Other methodologies

To construct sponge city, many cities infrastructures and facilities will be built on the surface of the earth and underground. In order to protect them, ground improvement techniques are conducted. Vertical drains and soil mixing (Shen et al., 2013a, b; Wang et al., 2013) are proposed. To achieve the low impact of the constructions, some technologies are proposed to widely used in the urban constructions, such as dewatering technology (Wu et al. 2015), jet grouting (Shen et al., 2013b,c; Wang et al., 2013) and methods to control the land settlement (Shen et al., 2014; Wu et al., 2015).

4. Perspectives

Sponge City is overall and efficient measure to improve anti-flood capacity and need to be planed based on the local conditions. This paper analysis the reasons that Wuhan suffers from floods frequently. By setting priority criteria, urban area is suggested to be the first region to construct Sponge City. Based on the reasons and conditions of Wuhan, this paper recommends recovery of water ecosystem and bioretention or rain gardens in constructions of Sponge City. GIS and RS technologies are also used in this paper to do the analysis.

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