Analysis and Research on the Regional Adaptability of Sponge City

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Abstract. Based on the three values of per capita water resources, precipitation, and sewage and wastewater discharge, our country's cities are divided into three types: water resource shortage, water quality shortage, and water pollution and water-logging risk cities. Comparing these three kinds of sponge cities, combining with the regional differences of my country's first-tier, new first-tier and second-tier cities, determine the types of sponge cities in my country's important cities. In view of the different water problems of the three types of cities, the regional adaptive construction plan of sponge cities is summarized.

1 Introduction

In recent years, many cities in my country have suffered from water-logging and water shortage problems. This is because rainwater is not properly discharged and used: urban drainage facilities are backward, and heavy water accumulates during heavy rains, resulting in flood disasters; urban rain and sewage are not diverted and rainwater is not reused, resulting in waste of rainwater. Sponge city is a Chinese expression of urban rainwater management. It refers to a city that is like a sponge and has good "flexibility", achieving a six-in-one diversified model of "seepage, retention, storage, purification, utilization, and drainage". In 2003, the initial concept of my country's sponge city was proposed by Yu Kongjian. He pointed out that "the natural wetlands on both sides of the river are like sponges, regulating the abundance of river water and alleviating drought and flood disasters."

Low-impact development originated from the United States, and was actually applied in Maryland in the 1990s. It uses decentralized, small-scale, low-cost green ecological technology to control storm runoff and pollution, so that the development area is as close to the natural hydrological cycle as possible[1]. In 2014, the British Parliament passed the "Flood and Water Management Act", stipulating that new projects must use a sustainable drainage system, and formulated the "National Standard." Sustainable drainage systems continue to extend the life of drainage systems through methods such as water quality, biodiversity and water resources management.

2 Regional division of sponge cities

There is a phenomenon of duplication in domestic sponge cities: if you want to build a sponge city from the root, you need to start with regional adaptability. The regional adaptability analysis of sponge cities in my country is based on the three values of per capita water resources, precipitation, and sewage and wastewater discharge. The cities in my country are divided into three types: water shortage, water quality, and water pollution and water-logging risk.

2.1 Current status of my country's water resources

The total amount of freshwater resources in my country is 2.8 trillion/m³, accounting for 6% of the global freshwater resources, ranking 4th in the world. However, my country's per capita fresh water consumption is only 2500 m³, which is 1/4 of the world average level. It is one of the countries with the poorest water resources per capita in the world.

China discharges up to 40 million tons of sewage every day, and 15 of the 27 major domestic rivers have been pollute to various degrees [3]. Our country's GDP water output is 33 yuan/m³, and developed countries' GDP water output is US\$13-14/m³. Water prices are generally low[4]. The price of water is not enough to make up for the cost. In southwest, water resources are rich but northern China is short of water resources.

In 2019, the total amount of water resources in the country was 2904.10 billion/m³, surface water resources were 2799.33 billion/m³, groundwater resources were 819.15 billion/m³, and the amount of groundwater and surface water resources was 104.77 billion/m³[5].

In 2018, domestic water consumption was 87.17 billion/m³, occupying 14.48% of total water; industrial water was 121.765 billion/m³, occupying 20.22% of total water; agricultural water was 368.23 billion/m³, occupying 61.16% of total water; artificial ecological environment supplementing water was 24.96 billion/m³, occupying the total amount of water is 4.15%[5].

2.2 The regional division standard of sponge cities

2.2.1 Water-resource type shortage cities

As water resources cannot meet the city's water demand, large-scale groundwater over-exploitation, lack of inflow

of sea water, and long-term river dry-off and other water environment problems in cities are water shortages.

The international water scarcity standard is defined by the Swedish hydrologist Marin Falken mark: a country with a renewable freshwater supply of less than 1700m³ per person per year means water shortages; less than 1000m³ per person per year, water resources are extremely scarce[6]. Li Gaoshe divided the annual rainfall of 500-800mm into semi-humid areas, and the annual rainfall of 300-500mm as semi-arid areas[7]. Therefore, cities with per capita water resources less than 500m³ per year are extremely water-scarce, and semi-arid areas with annual precipitation less than 400mm. Within this defined range, regional water resources are scarce and precipitation is small, and it is a water-source type water-scarce city.

Figure 1. Hu Huanyong Line (2000)

In the 20th century, National Central University Hu Huanyong proposed the Heihe-Tengchong Line, also known as the Hu Huanyong Line, as shown in Figure 1. The geographical distribution of China's population along the "Aihui-Tengchong" line shows a population distribution pattern that "36% of the land in the southeast half supports 96% of the country's population, and 64% of the land in the northwest half only supports 4% of the

population" [8]. In addition, the "Hu Huanyong Line" is also the natural boundary of China's social economy, ecological landscape, and meteorological precipitation: it is the boundary between semi-humid areas and semi-arid areas, and the boundary between farming civilization and nomadic civilization. At the same time, this line is also around overlapped to 400mm annual precipitation as shown in Figure 2.

Figure 2. Distribution of annual precipitation in China

Water source-type scarce water cities are located in the Haihe River Basin, the middle reaches of the Yellow River, the Shandong Peninsula, the middle and lower reaches of the Liaohe River, the northwest and some coastal cities, such as Tianjin, Shijiazhuang, Taiyuan, Yantai, Anshan, Dalian, etc[9]. Northern China is the most severe area. The extraction rate of surface water and groundwater has exceeded the actual capacity of local water resources. However, the supply and demand of water resources are still imbalanced, surface water has basically stopped flowing, and the groundwater level has been declining year by year.

2.2.2 Water-quality type scarce water cities

Due to the pollution of the water source, the water quality of the urban water supply is lower than the water use standards of the domestic, industrial, agricultural and other departments, resulting in water shortage, which is a water-quality shortage.

According to international water shortage standards, cities with per capita water resources greater than 500 m³ and less than 1000 m³ are severely water-deficient[6]. In my country's precipitation classification standard, areas with annual precipitation greater than 400 mm and less than 800 mm belong to semi-humid areas[7]. Within this defined range, the water resources of cities with a total sewage discharge of more than 40 million tons are in a state of pollution. This part of the city is not because of the low per capita water resources, nor is it that the water system is not abundant, but because of the lack of water caused by the water quality that does not meet the standards due to domestic, industrial, and agricultural pollution.

Water-quality deficient water cities are located in the Changjiang River, Huaihe River, and Pearl River basins: Bengbu, Suzhou, Wuxi, Kunming, Foshan, etc. The Liaohe River, Hailuan River, Huaihe River, and Yellow River basins are seriously polluted, and lakes such as Dianchi Lake, Chaohu Lake, Taihu Lake and Baiyangdian Lake are obviously eutrophication[9].

2.2.3 Cities at risk of water pollution and water-logging

According to international water scarcity standards, cities with per capita water resources greater than 1000m³ and less than 2000m³ are moderately water-scarce; cities with per capita water resources greater than 2000m³ and less than 3000m³ are mildly water-scarce[6]. In my country's precipitation classification standards, the annual

precipitation is greater than 800mm as humid areas [7]. The 800mm iso-precipitation line of my country's annual precipitation coincides with the Qinling-Huaihe line, which is the north-south boundary of China's geography. Within this defined range, the water resources of cities with a total sewage discharge of more than 40 million tons are in a state of pollution. This part of the city has heavy rainfall and serious pollution with water pollution and water-logging risk.

Reasons for water pollution and water-logging risk cities:

(1) Our country's urban development model is "on the ground first, then underground", which has caused the contradiction between the rapid urban development and the urban water-logging prevention system. The backward construction of urban drainage and flood discharge facilities is accompanied by problems such as blockage and aging of pipelines.

(2) Our country has developed a lot of wasteland in the process of urbanization, reducing permeable green land and increasing hardened land. The reduced water seepage capacity leads to rapid accumulation of rainwater, resulting in serious urban water-logging. Rainwater coerces urban pollutants and forms water pollution.

(3) Our country's developers tend to construct projects in low-level areas. This area is easy to be partially submerged in the rainstorm season. With the convenience of later demolition and the government's "land finance" support, developers can quickly obtain huge profits.

3 Types of cities in my country-based on the regional classification standard of sponge cities

Comparing the above three kinds of sponge cities' regional classification standards, and combining the characteristics of regional differences in my country's first-tier, new first-tier and second-tier cities[10], determine the types of sponge cities in my country's important cities.

Tier 1 cities: Beijing, Shanghai, Guangzhou, Shenzhen.

New first-tier cities: Chengdu, Hangzhou, Wuhan, Tianjin, Nanjing, Chongqing, Xi'an, Changsha, Qingdao, Shenyang, Suzhou, Zhengzhou, Dongguan, Hefei, Foshan.

Second-tier cities: Ningbo, Kunming, Fuzhou, Wuxi, Xiamen, Jinan, Dalian, Harbin, Wenzhou, Shijiazhuang, Quanzhou, Nanning, Changchun, Nanchang, Guiyang, Jinhua, Changzhou, Huizhou, Jiaying, Nantong, Xuzhou, Taiyuan, Zhuhai, Zhongshan, Baoding, Lanzhou, Taizhou, Shaoxing, Yantai, Langfang.

Table 1. Regional Classification of Sponge cities in my country's Important Cities (2019)[11]

NO.	city	classification	Water resources per capita /m ³	Water consumption per capita /m ³	Rainfall l/mm	Total sewage discharge/100 million tons	Total sewage treatment/100 million tons
1	Beijing	Water source type	165	182	590	20.4	19

2	Shanghai	Water quality type	199	313	1389.2	22.4	21.5
3	Guangzhou	Water source type	488	438	1820.7	23.2	--
4	Shenzhen	Water source type	198	423.3	1918.2	14.2	--
5	Chengdu	Water quality type	877	343	1434.2	12.4	12
6	Hangzhou	Water pollution and water-logging risk type	1815.8	298.9	1823.5	26.3	--
7	Wuhan	Water source type	317.3	326.9	1095.1	31.2	--
8	Tianjin	Water source type	51.8	183	436.2	8	4.9
9	Nanjing	Water quality type	560.3	488.6	1443.3	35.3	--
10	Chongqing	Water pollution and water-logging risk type	1690	249	1443.3	66.1	--
11	Xi'an	Water source type	219	196.3	538	8.3	--
12	Changsha	Water quality type	606.8	439.7	1296.5	31.4	--
13	Qingdao	Water source type	170.5	99.3	741.6	8	--
14	Shenyang	Water source type	158.7	328	444.9	23.2	--
15	Suzhou	Water source type	273	626.6	1117.7	13.5	--
16	Zhengzhou	Water source type	71.8	204.2	559.3	8.4	6.8
17	Dongguan	Water source type	284.7	213.2	1857.1	12	--
18	Hefei	Water source type	262.8	377	696.6	26.2	--
19	Foshan	Water quality type	511	388	1991.1	11.3	--
20	Ningbo	Water pollution and water-logging risk type	1430.8	239	2103	17.4	--
21	Kunming	Water pollution and water-logging risk type	1536	280	1000	15.9	8.7
22	Fuzhou	Water quality type	934.9	429.2	1548.2	4.2	3.6
23	Wuxi	Water quality type	575	298	1100	6.6	5.2
24	Xiamen	Water source type	219.6	156.8	1290.2	1.3	--
25	Jinan	Water source type	218.4	174.3	810.9	2.9	--
26	Dalian	Water source type	412	271.6	651.4	16.1	--
27	Harbin	Water source type	102.8	--	--	3	--
28	Wenzhou	Water pollution and water-logging risk type	1381.4	192.6	1912.3	15.2	--
29	Shijiazhuang	Water source type	178	293	554.8	25.9	--
30	Quanzhou	Water pollution and water-logging risk type	1747	61.8	--	4.3	--
31	Nanning	Water pollution and water-logging risk type	2041.4	599	1339	6.4	--
32	Changchun	Water source type	221.9	311.1	451.8	2.9	--
33	Nanchang	Water pollution and water-logging risk type	1318.9	573	1368.4	27.3	--
34	Guiyang	Water quality type	984.9	228.7	1132.6	9.1	--
35	Jinhua	Water pollution and water-logging risk type	2476.3	178.1	1985.4	8.5	--

36	Changzhou	Water quality type	513.5	548.2	1243.8	21.9	--
37	Huizhou	Water pollution and water-logging risk type	3163.1	539.5	1897	6.2	--
38	Jiaying	Water quality type	697.2	374.8	1505.3	15.3	--
39	Nantong	Water quality type	623.4	560.6	1088.5	34.8	--
40	Xuzhou	-	--	--	858.3	--	--
41	Taiyuan	Water source type	123.4	154.5	481.7	2.2	1.5
42	Zhuhai	Water quality type	921.3	306	2114	5.3	--
43	Zhongshan	Water quality type	525.4	575	1762.9	16.5	--
44	Baoding	Water source type	189	9.4	99	0.8	--
45	Lanzhou	Water quality type	751.1	450.2	251.4	5.6	--
46	Taizhou	Water pollution and water-logging risk type	1648	271	1765.7	14.1	--
47	Shaoxing	Water pollution and water-logging risk type	1461	398.6	1566.9	17.1	--
48	Yantai	Water source type	106	129.8	446.6	7.8	--
49	Langfang	Water source type	128.7	19.5	33.4	0.8	--

4 Analysis and solutions of problems faced by sponge city construction

After clarifying the types of sponge cities in my country's important cities, the regional adaptive construction plans of sponge cities are summarized for the different water problems of the three types of cities.

4.1 Analysis and solutions to the problems of water-sourced water-scarce cities

4.1.1 Insufficient rainwater recycling rate

4.1.1.1 Reservoir

The reservoir has the function of rainwater storage and can also reduce peak flow. It is suitable for communities and building green spaces that require rainwater recovery. Rainwater can be reused for green irrigation and pavement washing, saving land, and rainwater pipes are easy to access, but the construction cost is high.

4.1.1.2 Rainwater tank

The rainwater tank is a closed simple rainwater collection and utilization facility on the ground and underground, which is suitable for rainwater collection and utilization on the roof of a single building. Its storage volume is small and rainwater purification capacity is limited.

4.1.1.3 Rainwater garden

The rain garden is a shallow recessed green space that gathers and absorbs rainwater from the roof or the ground. It is an ecologically sustainable rainwater utilization facility that allows rainwater to infiltrate the soil through plants and sand to conserve groundwater; or to replenish urban water such as landscapes and toilets.

4.1.1.4 Treatment of curb openings

The curb opening is to introduce the road runoff rainwater into the biological retention facility for purification and storage.

4.1.2 Insufficient wastewater recycling rate

4.1.2.1 Planting ditches

Grass-planting ditch can collect, transport, purify and discharge runoff rainwater, and wet grass-planting ditch can also improve the effect of runoff pollution control.

4.1.2.2 Initial rainwater abandonment facilities

The initial rainwater abandonment facility discards the initial rainfall runoff that contains high concentrations of pollutants, reducing the difficulty of subsequent treatment of rainwater. Discarded rainwater is discharged into the municipal sewage pipe network, and is treated by the sewage treatment plant. It is suitable for roof rainwater down-pipes, runoff rainwater centralized inlets, etc.

4.2 Analysis and solutions to the problems of water-deficient cities

4.2.1 Serious water pollution

4.2.1.1 Sunken green space

In a narrow sense, sunken green space refers to green space within 200 mm below the surrounding paved ground or road. In a broad sense, sunken green space refers to green space that has a certain storage capacity and can be used to purify runoff rainwater, including biological retention ponds, infiltration ponds, wet ponds, Rainwater wetlands, regulating ponds, etc.

4.2.1.2 Biological retention facilities

Biological retention facilities as shown in Figure 3 are located in low-lying areas, and use plants, soil and microbial systems to store and infiltrate and purify runoff rainwater. They are suitable for buildings in communities, roads and green spaces around parking lots, and urban road green belts.

NOTE: If underlying soil infiltration rate <0.5"/hr, the underdrain and infiltration sump option may be used. The infiltration sump option must be designed to infiltrate the design storm volume in less than 72 hours.

Figure 3. The structure of an enhanced bio-retention design

4.2.1.3 Rain and sewage separation system

For communities with a large area, the transformation method of "retaining the confluence pipe as a sewage pipe and building a new rainwater pipe" is adopted, because the sewage collection system is more complicated and the amount of excavation is large.

4.2.1.4 Rainwater collection system

For municipal roads, the transformation method of "retaining the confluence pipe as rainwater pipes and constructing new sewage pipes" is adopted, because the rainwater pipes are large in size and the gutter can be moved to the green belt[12].

4.2.1.5 Matrix ratio of permeable layer and water permeability of underlying surface

The permeable layer structure adopts multi-layer design with better filtering effect and larger rainwater storage capacity, such as (permeable brick + sand + gravel). Among them, the (zeolite + vermiculite + ceramsite) mixed matrix has the fastest penetration rate, which can

bear the rainwater penetration of 11-29 times more than its own area[13].

4.2.2 Insufficient green area

4.2.2.1 Plant buffer zone

The vegetation buffer zone slows down the surface runoff velocity through interception and soil infiltration, and removes some pollutants, with a slope of 2%-6%. It is suitable for roads and other impervious surfaces, can be used as pre-treatment facilities for biological retention facilities, and can also be used as a waterfront green belt in urban water systems.

4.2.2.2 Green roof

Green roofs are divided into simple and garden styles as shown in Figure 9: the substrate depth of the simple style is no more than 150 mm, and the substrate depth of the garden style can exceed 600 mm when planting trees. It effectively reduces the total amount of roof runoff and runoff pollution load, saves energy and reduces emissions, and has strict requirements on roof load, waterproofing, slope, and space conditions.

4.3 Analysis and solutions of urban problems with water pollution and water-logging risk

4.3.1 Excessive hardened area

4.3.1.1 Permeable bricks, grass-inlaid bricks

Permeable bricks are suitable for squares, parking lots, sidewalks, and roads with small traffic and load, such as building and community roads, municipal roads and non-motorized roads.

4.3.2 Excessive rainfall

4.3.2.1 Wet pond

The wet pond has the functions of rainwater regulation, storage and purification, and can be designed as a multi-functional water regulation and storage body in combination with green spaces and open spaces: it can play normal landscape, leisure and entertainment functions at ordinary times, and it can play a regulation and storage function during heavy rains to realize multi-functional utilization of land resources.

4.3.2.2 Regulation pond

The regulating pond can reduce the peak flow and consists of water inlet, regulating area, outlet, slope protection and embankment. Make it permeable through reasonable design, supplement groundwater and purify rainwater.

4.3.3 Backward drainage network

Aiming at the problems of aging sewage pipe network, too small diameter, incorrect elevation and siltation of

upstream and downstream sewage, formulate a transformation plan to speed up the construction of sewage pipe network, expand the coverage of sewage pipe network, and increase the sewage collection rate. During the construction of the sewage pipe network, a strict reward and punishment system will be implemented and relevant standards will be refined.

4.3.4 Industrial, agricultural and domestic pollution

4.3.4.1 Rainwater wetland

Rainwater wetlands use aquatic plants to purify rainwater, which is an efficient runoff pollution control facility as shown in Figure 4. Rainwater wetlands are often built together with wet ponds, consisting of water inlets, front ponds, swamp areas, outlet pools, overflow and outflow outlets, slope protection and revetment, maintenance channels, etc.

Figure 4. The structure of rainwater wetland

4.3.4.2 Seepage well

Infiltration wells refer to facilities for rainwater infiltration through well walls and bottoms, and are suitable for buildings, roads and green spaces around parking lots in communities.

5 Conclusions

This article divides important cities across the country into water-source-type water shortages, water-quality-type water shortages, and water pollution and water-logging risk cities, in order to explore regional construction programs in a targeted manner.

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