

# Research on rainwater utilization potential and key utilization methods of sponge city in Kaifeng, China

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**Abstract.** China is carrying out the construction of sponge city vigorously. It is necessary to estimate the utilization potential of urban rainwater resources in order to ensure the implementation of sponge city planning and construction program. There are some problems in the existing calculation models of rainwater resource utilization potential. In view of these problems, we put forward a reasonable classification system of underlying surface, built a rainwater resource utilization potential calculation model suitable for the construction of sponge city, and applied this model in Kaifeng city, and put forward specific measures for the utilization of urban rainwater chain.

## 1 Introduction

There are some problems in the existing calculation models, such as:

(1) The calculation principle is not suitable for urban environment. Xu, X. X.(2000) etc. calculated the rainwater confluence potential based on the rainfall data of the loess plateau[1]. Feng, H. (2001) etc. proposed three kinds of rainwater resource utilization potentials, namely theoretical potential, realizable potential and practical potential, and discussed the calculation principle based on small watershed[2]. However, these studies focus on drinking water and rainwater harvesting irrigation in arid and semi-arid areas and are not fully applicable to urban environment.

(2) More qualitative analysis, less quantitative calculation. In terms of urban rainwater recycling, Song, J. X.(2003)etc. analyzed the necessity, possibility and sustainability of rainwater recycling in Xi 'an[3~4]. Li, Y. J.(2003)etc. analyzed the favorable conditions and utilization ways of rainwater resources in Taiyuan city [5].In terms of the calculation of urban rainwater resource potential, Yu, W.D.(2007)etc. divided urban built-up areas into impermeable areas, green garden areas and water areas[6].Huang, X.F.(2007)etc. calculated the potential of urban rainwater resources based on the principle of water balance[7]. Shen, Y.Q.(2015). used GIS as an auxiliary method to estimate the water resource potential of Xindu district of Chengdu by empirical formula method[8].These studies focus on the significance and approaches of urban rainwater recycling, but rarely involve quantitative studies.

(3) The classification system of underlying surface is unscientific. When calculating the utilization potential of urban rainwater resources, the urban underlying surface

is usually divided into three categories: permeable surface, impermeable surface and water surface, which is not in line with the actual situation of urban underlying surface.

## 2 Rainwater utilization potential

### 2.1 rainwater resource utilization potential

#### 2.1.1 Underlying surface classification of rainwater

For the above problems, we proposed an improved model. The classification of urban underlying surface is based on the characteristics of rainwater runoff and infiltration of different types of underlying surface. The result is shown in Fig 1.

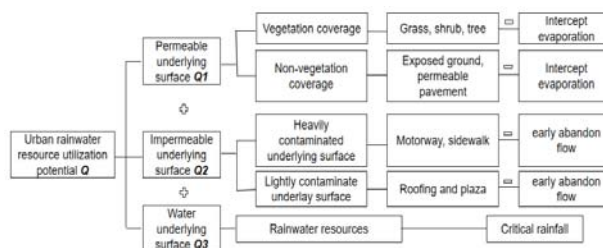


Fig. 1. City underlying surface classification system

#### 2.1.2 Utilization potential calculation of rainwater resource

The rainwater that exceeds the maximum capacity of the city is called critical precipitation, which is not within the calculation range. Urban rainwater resource

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utilization potential  $Q$  is composed of three parts, including impermeable underlying surface rainwater resource utilization potential  $Q_1$ , permeable underlying surface rainwater resource utilization potential  $Q_2$ , and water underlying surface rainwater resource utilization potential  $Q_3$ .

$$Q_1 = \sum_{i=1}^m (R_i - R_k) \times S_1 \times 1000 \quad (1)$$

$$Q_2 = \sum_{i=1}^m (R_i - R_a) \times S_2 \times 1000 \quad (2)$$

$$Q_3 = R \times S_3 \times 1000 \quad (3)$$

$$Q_t = \sum_{i=1}^m (R_i - r_a) \times S \times 1000 \quad (4)$$

Formula for calculating the theoretical utilization potential:

$$Q_s = Q_1 + Q_2 + Q_3 \quad (5)$$

Formula for calculating the realizable utilization potential:

$$Q_e = Q_s - Q_t \quad (6)$$

$R_i$ —process rainfall, mm;

$R_k$ —precipitation loss and the initial abandoned flow, urban impermeable underlying surface can be taken 4~6mm;

$m$ —precipitation times in a certain period, such as 1 year;

$R_a$ —vegetation interception, 0.3mm;

$r_a$ —critical rainfall, the maximum amount a city can hold in a single rainfall, 50mm;

$R$ —total precipitation for a period of time, mm;

$S_1$ —impermeable underlying surface, km<sup>2</sup>;

$S_2$ —permeable underlying surface, km<sup>2</sup>;

$S_3$ —water underlying surface, km<sup>2</sup>;

$S=S_1+S_2+S_3$ , km<sup>2</sup>.

### 3 Analysis on utilization potential of rainwater resources in Kaifeng City

#### 3.1 Overview of the research area

##### 3.1.1 Nature overview

Kaifeng city is located in the east of Henan Province, located in the south bank of the lower Yellow Rive. The landform is part of the alluvial fan plain in the lower Yellow River. The terrain is flat, the general trend of the landform is slightly inclined from the northwest to the southeast, the surface slope drops to 1/2 000 ~ 1/4 000, and the altitude is between 69~78 m. The average annual precipitation in this area is 662.8mm, and the rainfall in

July and August accounts for more than 65% of the annual precipitation. The average annual evaporation is 1 600 ~ 2 000 mm, among which the evaporation in May and June is the largest, accounting for 25% ~ 30% of the annual evaporation. The main recharge methods of shallow groundwater are meteoric precipitation infiltration, lateral infiltration of the Yellow River, canal leakage, irrigation return infiltration, etc. The groundwater flow is consistent with the slope of the terrain, and the drainage methods are mainly mining and evaporation. Kaifeng city is dotted with lakes and ponds, the total amount of water storage 4.1 million m<sup>3</sup>, so it is known as the “northern water city”.

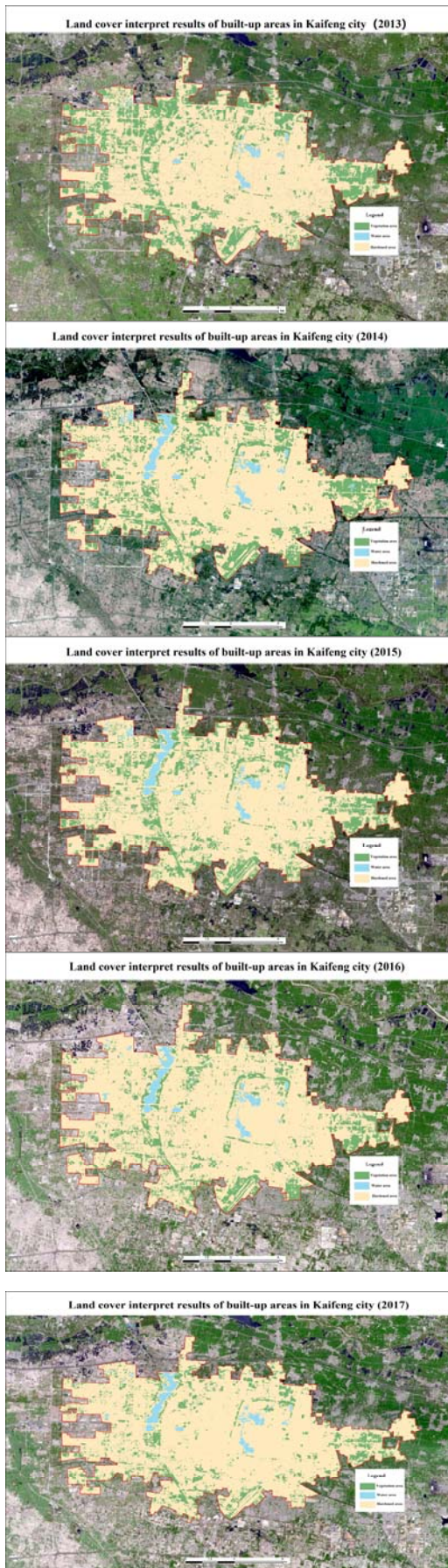
##### 3.1.2 Water resources

The local water resources of Kaifeng City are far from meeting the demand of water quantity and quality for the city's economic and social development, so the city has been relying on the water from the Yellow River for a long time. The region's water deficit. With the acceleration of economic and social development and urbanization, the urban water consumption continues to increase, and the sewage discharge continues to increase, and the contradiction between the supply and demand of water resources becomes more prominent. The supply of surface water is very limited, the total amount of yellow water is strictly controlled, and the groundwater cannot be over-exploited. Therefore, making full use of urban rainwater resources is an economical, quick and widely effective way. Rainwater recycling can not only solve the urban water resources crisis, but also bring a series of ecological environmental effects such as groundwater conservation, alleviation and recovery of land subsidence, climate regulation, air purification, strengthening urban greening, improving urban environment, changing urban drainage system, prevention and control of rain and flood.

#### 3.2 Utilization potential of rainwater resources in Kaifeng City

##### 3.2.1 Interpretation and calculation

By interpreting HD images(as shown in Fig.2), we obtained the land cover data of 144.6km<sup>2</sup> urban built-up area in Kaifeng from 2013 to 2017 (as shown in Table 1). The annual total runoff control rate of Kaifeng is targeted at 75%~85%[9]. According to the lower limit of control rate, we applied the model to Kaifeng and obtained relevant data (as shown in Table 2).  $R_k=6\text{mm}$ ,  $R_a=0.3\text{mm}$ ,  $r_a=50\text{mm}$ .



**Fig. 2.**High definition satellite image of land vegetation cover in Kaifeng from 2013 to 2017.

**Table 1** Land cover interpret results of built-up areas in Kaifeng city (2013-2017)

Year	Hardened area /km <sup>2</sup>	Vegetation area /km <sup>2</sup>	Water area /km <sup>2</sup>	Total /km <sup>2</sup>
2013	104.49	38.55	1.56	144.60
2014	106.62	33.75	4.23	144.60
2015	108.37	32.35	3.88	144.60
2016	116.31	24.34	3.95	144.60
2017	119.86	20.93	3.81	144.60

**Table 2** Rainwater resource utilization potential calculation results in Kaifeng city

Year	Annual rainfall R/mm	Impermeable underlying surface Q <sub>1</sub> /m <sup>3</sup> ×10 <sup>6</sup>	Permeable underlying surface Q <sub>2</sub> /m <sup>3</sup> ×10 <sup>6</sup>	Water underlying surface Q <sub>3</sub> /m <sup>3</sup> ×10 <sup>6</sup>
2013	409.7	25.192539	15.296640	0.639132
2014	645.2	41.187306	21.078563	2.729196
2015	764.8	43.402185	23.786955	2.967424
2016	424.3	27.542208	9.810643	1.676117
2017	529.6	35.538490	10.714067	2.017776
Year	Theoretical utilization potential Q <sub>s</sub> /m <sup>3</sup> ×10 <sup>6</sup>	Critical rainfall Q <sub>i</sub> /m <sup>3</sup> ×10 <sup>6</sup>	Realizable utilization potential Q <sub>e</sub> /m <sup>3</sup> ×10 <sup>6</sup>	Utilization target Q/m <sup>3</sup> ×10 <sup>6</sup>
2013	41.128311	4.005420	37.122891	27.842168
2014	64.995065	3.181200	61.813865	46.360399
2015	70.156564	0.000000	70.156564	52.617423
2016	39.028967	0.000000	39.028967	29.271725
2017	48.270333	4.077720	44.192613	33.144460

## 4 Rainwater key utilization methods of sponge city

### 4.1 Optimization measures of urban underlay surface

According to the law of annual variation of urban rainwater utilization potential and its relationship with underlying surface, the optimization measures of different types of underlying surface are put forward. Such as through Water surface can be used to increase the vegetation coverage, the construction of sunken green space, grass gully, rain garden, etc., to increase the space of rainwater infiltration, the formation of rainwater retention, in the slow process of infiltration, rainwater purification. Impermeable cushion surface can use green roof, green wall, balcony garden and other ways of stagnant storage or purification of rainwater, or in the residential area, the city road and other suitable location to set up underground storage module. Under the water area cushion surface can pay attention to artificial wetland, ecological embankment, ecological floating island, urban landscape sponge cell construction. All rainwater collected can be used in the dry season or the season when water is needed for maintenance of green plants, road cleaning, vehicle washing, urban landscape water body construction, etc., in order to complete the "sponge water release". The sponge cell design for storm water management and utilization of the roof and impermeable hardened floor is shown in Table 3 and Table 4.

**Table 3** Roof rainwater management and utilization cell design

Methods	Facilities	Singl e-family homes	Multi-storey, high-rise residential	Public buildings	Larg e roof
Collection and recycling	Above-ground water storage tanks	●	◎	◎	○
	Wet pond, landscape water body	●	●	●	●
	Reservoir	○	◎	●	●
	Ditch transfer	◎	●	●	●
	Abandon flow + pipeline transfer	◎	◎	◎	◎
Infiltration	Breakout emissions	◎	●	●	●
	Ecological water infiltration	◎	●	●	●

	on				
	Buried infiltration	○	○	◎	◎
Regulation and discharge	Wet pond, landscape water body	○	●	●	●
	Buried storage tank	○	◎	◎	◎

Note: ●—preferred; ◎—optional; ○—not recommended.

**Table 4** Watertight hardening ground rainwater management utilization cell design

Methods	Facilities	Courtyard	Pavement	Square	Driving road	Parking lot
Infiltration	Permeable pavement	●	●	●	◎	◎
	Straw brick paving	●	◎	◎	◎	●
	Concave greenbelt	●	●	●	●	●
	Grassed ditch	●	●	●	●	●
	Grassed lowland	◎	●	●	●	●
	Biological stranded	◎	◎	●	●	●
	Dry pond	◎	●	●	●	●
	Infiltration trench	○	◎	●	○	○
	Infiltration discharge	○	◎	●	○	○
	Penetrating Wells	○	◎	◎	○	○
Collection and recycling	Infiltration pool	○	○	◎	○	○
	Grassed ditch for water	●	●	●	○	○
	Pebble ditch	●	●	●	◎	○
	Wet pond, water body	●	●	●	◎	○
	Buried pool	◎	◎	◎	○	○

	(tank)					
Regulation and discharge	Wet pond, landscape water body	○	●	●	●	●
	Buried storage tank	○	◎	◎	◎	◎

Note: ●—preferred; ◎—optional; ○—not recommended.

### 4.2 Rainwater chain design of sponge city

Through reasonable design between cells, the runoff path of rainwater is connected to form a rain water chain (as shown in Fig.3), thus forming an urban sponge in harmony with nature.

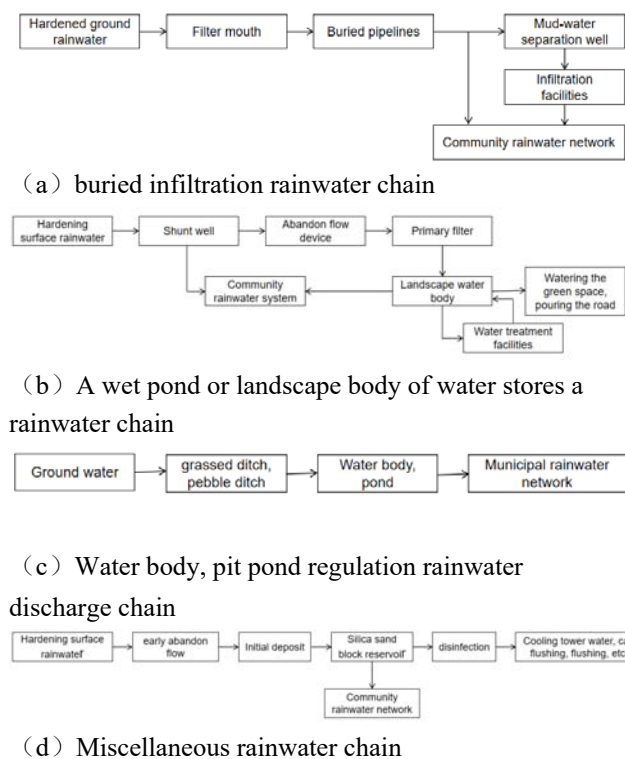


Fig.3.Design of sponge city rainwater chain

### 5 Conclusions

Kaifeng has long relied on the Yellow River to make up for its lack of water. The available amount of surface water is very limited, the amount of water diverted from the Yellow River is strictly controlled, and the groundwater cannot be over-exploited. Making full use of urban rainwater resources is an economical, fast and effective way. But, urban construction has its own characteristics, we need to carry out scientific planning according to the objective conditions of the city, gradually promote the construction of sponge city, so as to improve the ecological environment of the city, improve the quality of the city.

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