Study on the Potential Development of Rainwater Utilization in the Hilly City of Southern China

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Abstract. Aimed at the current flood problems and the contradiction between supply and demand of water resources in the southern cities of China, the comprehensive utilization of *Urban Rainwater Resources* (URRs) is a significant solution. At present, the research on the comprehensive utilization system of urban rainwater resources in China is still immature, especially the lack of a comprehensive method for the comprehensive utilization of the rainwater and flood resources in the south. Based on the current mode for utilization of URRs at home and abroad, Fenghuang County in Hunan Province was taken as a case of study，which is a typical mountainous city in the southern China. And the potential development of URRs was simulated and evaluated with a comparison of before and after the exploitation and utilization of URRs in this paper. The reduction effect of flood and waterlogging on the ancient city area is analyzed from SWMM. The simulation results show that the potential of exploitation and utilization of URRs in Fenghuang county is remarkable under the mode of exploitation and utilization which is given priority to flood prevention and control, and the annual development potential is 4.865×10^5 m^3. The rainwater utilization measures of flood control effect is obvious with this mode, and the relevant research results can provide theoretical and technical support for enhancing urban water security capability, water conservation capacity, and disaster mitigation of urban flood.

1. Introduction

With the continuous improvement of the level of urbanization in China, the problems of urban water shortage and rain flood disasters are becoming increasingly prominent. In recent years, most cities in southern China suffered heavy rains during the flood season, and serious floods and waterlogging occurred, which caused great economic losses and casualties. Heavy rainfall intensity and long duration are the main characteristics of urban floods in southern china. The torrents in mountain cities happened frequently. The shortage of flood carrying capacity often leads to a long time for flood stage exceeded the warning value and affects a wide range of area and some other serious disaster. In view of this prominent city problem, by integrating the system of comprehensive utilization of city rainwater resources of different city permeable units (roof, surface hardening impervious element, the green river water permeable unit, etc.), generalizing rainfall flood comprehensive utilization measures in multi-dimensional through the numerical simulation technology, aiming at natural infiltration natural purification, the comprehensive utilization of rain flood potential evaluation analysis is the main

measure to minimize the risk of disasters, and the key to reasonable planning of city flood control and drainage system of science.

As an important part of city water circulation system, if the rainwater resources can be fully utilized by the rational and scientific technology, then the *Urban Rainwater Resources* (URRs) in southern area will be effectively adjusted, and the water ecological environment will be effectively improved. The research and application of rainwater resources comprehensive utilization technology is the earliest development and utilization mode of water resources [1]. How to select the appropriate comprehensive utilization model of URRs and evaluate the potential of development and utilization is a concerned problem of current research [2]. In the early 1980s, Th.M. Boers put forward the concept of rainwater harvesting and utilization from the three characteristics of rain and flood, and advocated that the irrigation efficiency of surface crops could be improved by rainwater runoff accumulation and utilization measures [3]. Then in 1990s, the United States proposed Low Impact Development (LID) design concept, which has been used in practice in Maryland, the study confirmed that the measures have a positive impact in easing regional water problems [4].

Since the 21st Century, with the development of LID concept, some of the same period of urban development and design concepts came into being, such as water sensitive urban design, sustainable development of urban drainage system. Especially in the new urban planning, the use of LID and utilization relative to the transformation of the old city can greatly reduce construction time and economic costs [5]. The *United States Environmental Protection Agency* (USEPA) issued the *Low Impact Development Design Strategies* in 2000. With the development of rainwater resources theory, other developed countries, such as Australia, Greece, Britain, Poland and Japan have also followed the example and combined with their own practice to study and apply the related comprehensive utilization mode of URRs [2][14]. For example, based on the concept of urban water sensitivity, Australia proposed a new urban design scheme for waterlogging, mainly focusing on *purification* and *utilization*, emphasizing the *natural design* of the urban water cycle process; Japan mainly promoted facilities and applications for infiltration and storage levels, and their flood release systems and rainwater storage systems emphasized *stagnation* and *platoon*; Britain put forward the idea of *Sustainable Urban Drainage Systems* (SUDS), which is based on prevention, with source control as its technology, site control and regional control as its planning scope [6]. In 2013, China proposed sponge city construction mode, referenced LID measures which applied from the source control, ecological restoration and protection, to achieve the effect of *Penetration*, *Retention*, *Storage*, *Purification*, *Utilization*, *Drainage*, and thus formed a complete set of technical system. The research on the utilization of rainwater resources in China has been heating up. In 2002, Song Jinxi et al took Xi'an city as the research area, explored and studied the rainwater infiltration and storage in the region, and achieved the utilization of rainwater resources and other aspects of their work [7]. Li Junqi et al summed up and analyzed several main forms of rainwater utilization in German cities, such as rainwater collection and utilization system, rainwater utilization system of roof garden, rainwater interception and infiltration system, rainwater utilization system in ecological community, and put forward the suggestions and management of city rainwater utilization in China [8]. Zhu Qiang et al thought that rainwater harvesting and utilization is an integral part of water resources development, and it is an irreplaceable form of water resources development especially in many water-lacking mountain areas. Therefore, he suggested that the amount of rainfall should be evaluated as a total amount of water resources [9]. Che wu et al took a residential district in Tianjin as the research area, combined with the actual situation of rainwater utilization, and used water balance analysis method to design waterscape. The method is helpful to realize the normal development of waterscape construction under the increasingly shortage of water resources [10].

Referring to the research status of the comprehensive utilization and potential analysis of URRs, the research areas are mostly concentrated in small scale experimental areas or northern resource-based water shortage cities. The hydrological effect analysis of urbanization has experienced the transition from traditional development to rain flood utilization, with the planning and implementation of the utilization mode of rainwater resources, that is, a mapping of the urban construction concept transformation. With the domestic sponge city pilot carried out, related research also increased, but few

researches in the city of southern mountainous areas, especially in the southern humid mountain city which are characterized by complicated topography, numerous rivers and frequent floods. And the analysis results of comprehensive utilization and development potential of rainwater resources in the whole city are also relatively insufficient.

2. Materials and Utilization Mode

2.1. Study Reach

Fenghuang county, with a large spatial and temporal variation of precipitation, is a typical hilly city of southern China. The terrain is dominated by hills, the downstream and river valley flat are complex distribution. The surrounding areas of the ancient city are mostly hilly areas, with relatively high elevation difference and poor geological conditions, and the soil is basically dominated by bare rocks and gravel. The location of Fenghuang county is shown in figure 1. The urban land type is complex and the ancient city district is dominated by residential land. The commercial land distribution is in the East, the public management and service ones located in the western, commercial service land distributed on both sides of the Tuojiang and Hongqiao Road. The water resources in Fenghuang County are relatively abundant, and the amount of surface water and ground water is almost zero because of the mountain location. The total water resources of the county is 1.31×10^9 m^3, and the amount of water resources is about 3096m^3 per capita. Regional location is shown in the Figure 1.

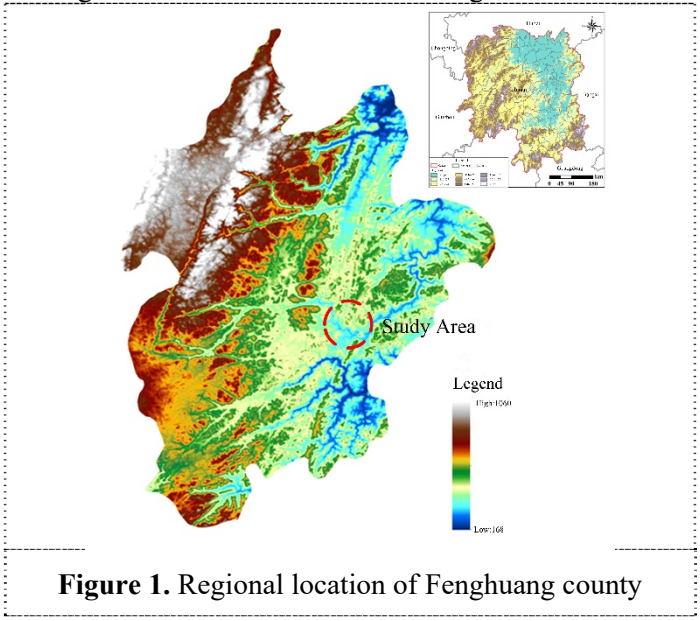

Figure 1. Regional location of Fenghuang county

2.2. Utilization Mode of URRs

The types of city underlying surface including impervious units (building roof, impervious road/site etc), semi permeable units (general parking lot ground, the gravel permeable asphalt no underground construction, the pervious units (park, green lawn and shrub forest) and strong permeable units (parking lot, sidewalk and rainwater garden with changing soil or strong permeable treatment.) and water units, regardless of the underlying surface can be what kind of the three basic types of rainwater resources comprehensive utilization mode, namely Rainwater Infiltration Mode (RIM), Collection and Reuse Mode (CRM) and Discharge Control Mode (DCM). Various types of modes contain different specific measures, as it is shown in the Table 1.

Table 1. Basic utilization mode of URRs

Mode	Measures	Features/effects	Application scope
RIM	Sunken green space, permeable pavement, special sponge material, sink / well / soakaways	Own rainwater is no longer discharged, and the surrounding surface runoff flows into the green land rapidly to seep in	Sidewalks, courtyards, squares, parking lots, bicycle lanes and small traffic lanes in the district
CRM	Collect pipelines, initial runoff, abandon facilities, storage and drainage basins, treatment facilities, clear water storage tanks, return pipelines, rain pools, ground open rainwater basins	Rainfall runoff collection and storage. After proper purification, the utility mode can be used for filling, flushing, car washing, landscape and the like, and can be integrated with the surrounding landscape water bodies	Roof, roads, courtyards, squares. Rainwater is collected from the collecting pipeline to the initial runoff rejection tank, and then stored in the water storage unit
DCM	The detention facilities, such as rainwater ponds, storm depressions and detention basins, are built with underground large storage culvert, stagnant storage tunnel or stagnant storage tank; flow control wells and flow weirs	Control, detention facilities combined, the peak and process control into the downstream water, the peak, the peak effect, reduce the impact on the downstream drainage system	In the proper place before the rain discharge area, the rain and flood will lead to the river and lake system, with the help of the rain

However, considering the regional characteristics, the three basic technical modes can be organically combined to form a scientific and optimal comprehensive utilization system of rainwater resources in practical application [13]. In the cities dominated by water logging prevention and control in southern China, suitable technical models for reducing rainwater runoff, controlling rainwater discharge and relieving flood and drainage pressure should be selected. In general, the main purpose of the collection is to increase infiltration, regulate and control emissions, and collection reuse. The main purpose of the collection is to retain the water supply and take into account the water replenishment function of the landscape [14]. From the city construction project to waterlogging prevention mainly to reduce emissions of rain set the source control measures for the purpose, and make full use of the ability of urban rivers and lakes, ponds, lakes as appropriate to increase the regulation of rain and flood measures, improve the city drainage system of flood control ability [15].

3. Results and Discussion

3.1. Assessment Methods

As a typical city in the southern hilly area, Fenghuang county is greatly affected by temperate monsoon climate. The average annual precipitation is 1308.1 mm, and precipitation decreases with the change from northwest to southeast. The flood season is concentrated from May to July. Overall, Fenghuang County annual average runoff is about 13.1 m^3, the annual runoff coefficient is in the 0.50 to 0.55 intervals. The total urban runoff is abundant, but annual change is larger. The utilization of rainwater resources and the total runoff are considerable great. According to the general characteristics of the water resources in Fenghuang county, the comprehensive utilization mode of urban rainwater was adopted. The urban underlying surface can be divided into five parts with the corresponding units of hydrological characteristics, including impermeable units, semi permeable units, permeable units, strong permeable units and water units. The patterns of rainwater development and utilization of southern cities are shown in Figure 2.

As far as the contradiction between supply and demand is concerned, the problem of water shortage is caused by poor water quality in most southern cities. The above-mentioned development and utilization patterns can promote the efficient utilization of urban rainwater resources. The scale of construction and related technical parameters can refer to the local planning of rainwater utilization, such as the relevant action requirements mentioned in *Pollution Prevention Action Plan of Hunan Province* proposing to improve the efficiency of urban water recycle. And the rainwater storage facilities with the volume of more than $30m^3/km^2$ are also demand on the pavement construction. Therefore, the experience of comprehensive utilization of rainwater in that mode is regarded as a certain degree of

replication and popularization for other southern cities. To further evaluate the development potential of comprehensive utilization of rainwater resources in southern China will help to reduce the level of urban flood and waterlogging, and to ease the contradiction between water supply and demand [12].

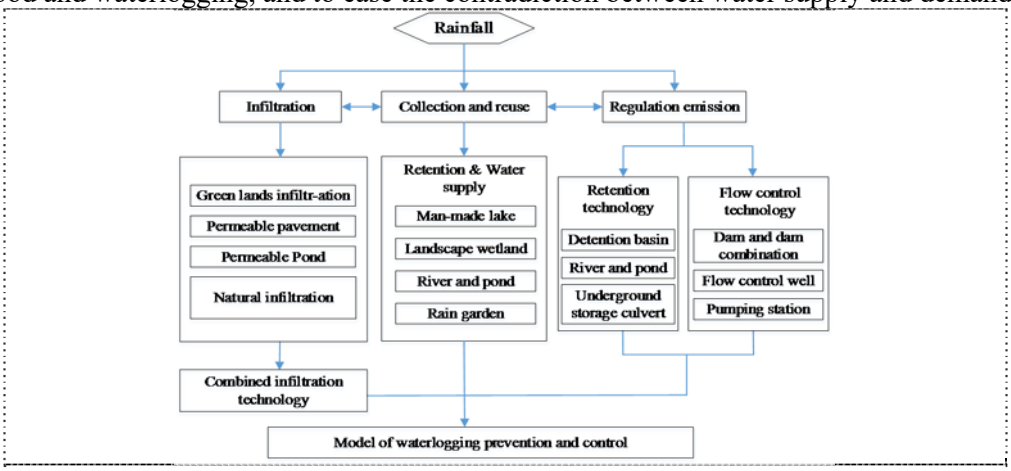

Figure 2. Comprehensive utilization mode of urban stromwater in South China

3.2. Development Potential Analysis

Development potential should be kept in the sum of the local rain water for restoring the ecological balance before regional development and construction under natural conditions and present technical levels. Development potential on comprehensive utilization of URRs could be aimed at the urban natural geography, social economic conditions and the city development prospect. For rainwater utilization research in the typical southern hilly city, SWMM can be used to simulate and analysis runoff coefficient and runoff control effect in 1 years design precipitation. The comparison of the present condition and rainwater utilization are shown in Figure 3 and Figure 4.

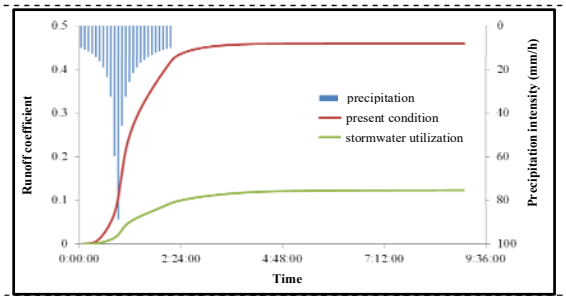

Figure 3. Comparison of runoff coefficient control

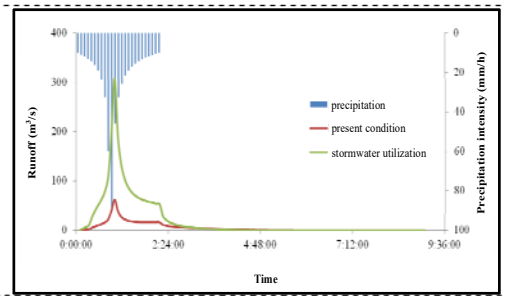

Figure 4. Comparison of runoff control

In the calculation of potential should choose appropriate standards, rainfall control rate of 80% to 90% is relatively reasonable in general. Therefore, the design storm in the calculation of comprehensive utilization of rainwater resources can be used in 1 years as the standard.

If there is a daily rainfall series, the comprehensive utilization potential of rainwater resources can be calculated by the daily rainfall series method. The formula is as follows.

$$W_p^i = 0.1 \cdot P^i \cdot (\varphi_2 - \varphi_1) \cdot F \tag{1}$$

$$W = \sum_{i=1}^{n} W_p^i \tag{2}$$

$$P^i = \begin{cases} I_s & I^i \geq I_s \\ I^i & I^i < I_s \end{cases} \tag{3}$$

In formula: W_p^i represents the potential of comprehensive utilization of rainwater resources with the daily rainfall numbered I, unit is ten thousand m^3; W represents annual comprehensive utilization potential of rainwater resources, equals to the sum of all the rainfall during the year and the potential of the comprehensive utilization of rainwater resources, unit is ten thousand m^3; i represents daily rainfall number; φ_1 and φ_2 represents the comprehensive runoff coefficient before and after urban development; F represents urban area, unit is km^2; P^i represents daily calculation rainfall, if the actual precipitation I^i exceeds the design precipitation I_s, it equals to I_s, it equals to I^i, unit is mm.

If there is only the average annual precipitation, there is no daily rainfall series, or only by using the annual average precipitation method for rough estimation, the formula is as follows.

$$W_p = 0.1 \cdot \alpha \cdot P \cdot (\varphi_2 - \varphi_1) \cdot F \quad (4)$$

In formula: annual average precipitation P (mm); comprehensive utilization rate of annual average rainwater resources α; other parameters are the same as mentioned above.

For the design storm of 1 year, the potential of comprehensive utilization of rainwater resources in Fenghuang county with the method of annual average rainfall is 495 thousand m^3, the synthetic utilization potential of SWMM is close to that of 486.5 thousand m^3. Therefore, the two methods have certain accuracy, and can be used as an assessment of comprehensive utilization potential of URRs.

4. Conclusion

For the southern cities of China, the URRs during the flood season are important unconventional water resources. Meanwhile, the comprehensive utilization of URRs is of strategic importance for the protection of urban water security. The southern cities with abundant water resources but poor water quality should focusing on waterlogging control and carry out the research work on rainwater utilization. In the assessment of comprehensive utilization potential of URRs, through a comparative evaluation of the flood disaster reduction effected by the before and after development and utilization of rainwater resources in the typical southern city，the study found that the south hill area suitable for city flood control and drainage of rainwater utilization mode, and the mode of rainwater utilization have huge development potential and good applicability. The related research work in the future should be encouraged to carry out comprehensive utilization of city rainwater resources, integrate distributed research into a system and expand the scale of construction appropriately. Through the effective control and management of the urban rainwater, the urban water condition and the habitability of the city will be improved.

In the light of the existing research results, there are still some problems that have not been included in the statistical category of the potential of exploitation and utilization of URRs. Such as the urban ecological system, its upstream and downstream hydrological and hydraulic links can't be artificially separated, so that the downstream urban ecological environment should be taken into the upstream city's rainwater resource request account. Although the rainwater resources are huge, it can't be effectively utilized. Therefore, this part should not be considered as a part of the potential, and the flood control and drainage capacity of the city need to be considered. Understanding the variety of rainwater resources utilization, the evapotranspiration is an indispensable utilization form in the ecological environment, increasing local available water evaporation can greatly adjust the local climatic conditions, therefore, evapotranspiration should also be considered as a part of the potential use of rainwater resources.

Acknowledgments

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