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Research and Applications of the Urban Rainwater Resource Utilization in the Pearl River Basin

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Abstract: As an important economic zone in southern China, the Pearl River Basin is faced with the challenges of uneven distribution of water resources in time and space, the contradiction between supply and demand exacerbated by urbanization, and water pollution. Taking Shenzhen City as a typical case, this paper focuses on urban rainwater resource utilization in the Pearl River Basin, and through the analysis of roof and ground rainwater collection technology, purification treatment process and diversified utilization ways, the rainwater resource technology system adapted to the monsoon climate characteristics of the Pearl River Basin is constructed, emphasizing the anti-typhoon, heavy rainfall treatment and the integrated design of "seepage, stagnation, storage, net, use and drainage". Shenzhen's experience shows that policy support, technological innovation and public participation are key to the success of rainwater recycling. The utilization of rainwater resources in the Pearl River Basin should be combined with local climate, economic and geographical conditions, and intelligent monitoring, low-cost purification technology and innovative financing models should be developed in the future. Although the technology system has achieved remarkable results in highly urbanized areas, its popularization in low-urbanized areas still needs further research. This study provides a sustainable water resource management plan for the Pearl River Basin and similar climate zones, which has both economic and ecological value, and provides a technical reference for coping with extreme rainfall under climate change.

Keywords: Pearl River Basin, urban rainwater, resource utilization, rainwater collection, rainwater treatment

1. Introduction

As an important economic zone in southern China, the Pearl River Basin is faced with the challenges of uneven distribution of water resources in time and space, the contradiction between supply and demand exacerbated by urbanization, and water pollution. In this context, the utilization of urban rainwater resources has become a key way to alleviate the shortage of water resources and improve ecology. This study focuses on the Pearl River Basin to explore the technical system of rainwater collection, treatment and reuse and its application potential.

Through the construction of technical systems (such as roof/ground rainwater collection and purification treatment) and case studies (taking Shenzhen City as an example), this study evaluated the benefits of rainwater reclamation in flood peak reduction, groundwater recharge and heat island effect reduction. Core issues include how to cope with heavy rainfall in monsoon climates, optimize low-cost and efficient technologies, and promote the "sponge city" model. This paper aims to

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provide a sustainable water resource management scheme for cities in the Pearl River Basin, with both economic value (e.g., annual savings of hundreds of millions of yuan) and ecological benefit (alleviating waterlogging and improving water quality), and provide reference for similar climate areas. In the future, it is necessary to combine intelligent technology and policy innovation to further promote the application of rainwater resources in a wider range.

2. Overview of the study area

The Pearl River Basin is an important river system in southern China, and its delta area is one of the most developed and dynamic economic zones in China. The river basin is mainly located in southern China, covering six provinces (Yunnan, Guizhou, Guangxi, Guangdong, Hunan, and Jiangxi) and two special administrative regions (Hong Kong and Macao), covering an area of about 454,000 square kilometers. It is the second largest river system in China.

The Pearl River Basin is located in the tropical and subtropical monsoon climate zone, with an average annual precipitation of 1000-2200 mm [1] and an average annual runoff of 336 billion cubic meters [2], second only to the Yangtze River in China. The Pearl River system consists of the Xijiang River (originating in Wumeng Mountain in Yunnan Province) as the main stream, and the Beijiang River, Dongjiang River and the Pearl River Delta rivers as tributaries.

Although the Pearl River Basin is one of the regions with the most abundant water resources in southern China, the spatial and temporal distribution of precipitation is uneven due to the influence of the East Asian monsoon [3]. The upstream area is rich in water resources, while the downstream area is affected by seasonality. In the case of global warming, the frequency of extreme weather (drought, precipitation, etc.) is also increasing, which has a huge impact on the social economy. At the same time, with the rapid development of urbanization in the Pearl River Basin, the contradiction between supply and demand is also increasing with the rapid growth of population. For example, the Dongjiang River Basin, part of the Pearl River Basin, accounts for only 18% of Guangdong's water resources but supports nearly half of the province's economic output. In addition, water bodies in the Guangdong-Hong Kong-Macao Greater Bay Area have also been damaged in recent years with various types of pollution, and the problem of water shortage has gradually become prominent [4]. Looking at the six provinces in the Pearl River Basin, the average population density of the region in 2018 was 2.1 times the national average population density, and the regional GDP accounted for 12% of the national GDP. The level of economic development in the basin is extremely unbalanced, the degree of water resources exploitation and utilization is uneven, and the capacity of water resources supply and security is insufficient [5].

Urban rainwater resource utilization refers to the collection, storage, treatment and reuse of rainwater by scientific means, so as to alleviate the shortage of water resources and improve the urban ecological environment. With the increasing demand for water resources in the Pearl River Basin, the importance of rainwater resource utilization is also becoming increasingly prominent. One of the innovative applications of urban rainwater resource utilization is sponge city, whose core concept is to let the city absorb water and store it during rainfall and release it during drought. Now China is vigorously promoting the "sponge city" pilot, which can be further expanded in the future [6]. There is also the technical system of rainwater resource utilization that still needs to be improved, and it can be generally optimized from the direction of "low cost" and "high efficiency". In general, urban rainwater resource utilization has great value both in ecology and economy, and its development prospect is quite considerable.

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3. Research method

3.1. Technology system construction

The reasonable construction of the technical system of rainwater resource utilization is the basis of urban efficient utilization of rainwater. Based on the climatic characteristics of the basin, the development of the cities in the basin and the demand for water resources, a multi-level and multi-objective technical system of urban rainwater utilization in the Pearl River Basin with applicability, rationality and management convenience should be established.

3.2. Application case analysis

Through the analysis of typical rainwater resource utilization cases, the root causes of problems, influencing factors and potential solutions can be found. Its core role is to combine theory with practice to help us understand problems more deeply, optimize decisions and improve practical ability. The following case analysis will help us to study and apply urban rainwater resource utilization in the Pearl River Basin.

4. Construction of urban rainwater resource utilization technology system in the pearl river basin

4.1. Rainwater harvesting technique

Rainwater harvesting technology is an important part of urban rainwater resource utilization, which is a process of systematic collection and storage of natural precipitation through engineering means. Rainwater collection systems include roof rainwater collection systems and ground rainwater collection systems [7]. This study mainly focuses on urban rainwater collection technology.

4.1.1. Roof rainwater harvesting technology

Roof rainwater collection technology is a technology that converts rainwater into water resources through a specially designed collection, storage and treatment system using the roof of a building as a rainwater collection surface. Now widely used in many buildings, the technology has the advantages of less pollution and high collection efficiency. The system consists of the top collection area, the transmission pipeline, the storage device and the necessary water treatment equipment [8], and after a series of subsequent disinfection and purification, it can become a water resource that we can use. The distribution of precipitation time in the Pearl River Basin is uneven, which is greatly affected by monsoon, and the regional climate factors, such as typhoon landing, sometimes prove that the establishment of a roof rainwater collection system needs to be tailored to local conditions. The roof rainwater collection system in this area should have anti-typhoon structure (strengthen the wind resistance level of the support), large flow treatment (designed according to 50mm/h short-term heavy rainfall), and anti-mildew measures (silver ion antibacterial).

4.1.2. Surface rainwater harvesting system

A surface rainwater collection system is a technical system for rainwater resource utilization by intercepting, diverting, purifying and storing surface runoff. Compared with the rooftop rainwater collection technology, the system has a large catchment area, and a considerable amount of collection, but also has many complicated pollutants. Different ground types lead to different collection systems. For hardened ground systems (squares and roads), curb collection and sand settling wells or linear drainage ditches and module pools are mostly used, while for natural ground types (parks and green

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spaces), grass ditches and rain gardens are used. In the Pearl River Basin, the surface rainwater collection system should also have the ability to resist typhoons and handle heavy rainfall. The most important thing is that with the high-density urban development in the Pearl River Basin, the system should adopt the six-in-one technical route of "infiltration, retention, storage, net, use and drainage" to maximize the efficiency of rainwater collection resources and cope with the high-water demand brought by the industrial development and population growth in the Pearl River Basin.

4.2. Rainwater treatment technology

Rainwater treatment technology refers to a technical system that purifies collected rainwater through physical, chemical or biological methods to meet the standards for use [9]. According to the different uses of rainwater and water quality standards, urban rainwater generally needs to be treated to meet the requirements of use, and a variety of conventional water treatment technologies can usually be used for rainwater treatment. Rainwater treatment technology mainly includes precipitation, filtration and disinfection steps. Rainwater first enters the sedimentation tank through the collection system to separate the solid particles from the water, then filters out the particles through the filter, and finally is disinfected by ultraviolet light or adding disinfectant, thus completing the process of rainwater treatment [10].

4.3. Construction of urban rainwater resource utilization technology system in the pearl river basin

As shown in Figure 1, rainwater resources enter the urban water storage system after collection and treatment. Rainwater resources are mainly used in three aspects: municipal utility, industrial water and ecological water replenishment. The water use process is monitored and managed, and the use of rainwater resources is managed through intelligent monitoring, operational management, and policy standards in order to maximize the efficiency of the entire rainwater resource utilization system. The utilization of urban rainwater in the Pearl River Basin also needs to conserve water sources, slow down urban rainwater flooding and groundwater decline, control rainwater runoff pollution, improve the urban ecological environment and so on. This basin is heavily affected by the monsoon, and the rainfall has the characteristics of uneven distribution in time and space. There is more heavy rainfall, which has a great impact on the urban drainage system. Therefore, the rainwater utilization system of the Pearl River Basin needs to be diversified. Considering that the urbanization level of the Pearl River Basin is relatively high, the control of stormwater runoff pollution is also an important topic. Urban stormwater runoff pollution control measures include engineering measures (detention ponds, infiltration facilities, and plant treatment facilities) and non-engineering measures (management methods, economic means, policies and decrees) [11]. According to these principles, the urban rainwater utilization system is designed, and its economic (water saving amount, income) and environmental benefits (carbon emission reduction, runoff reduction, heat island mitigation) are analyzed by a benefit assessment model. Relying on the economic level of the Pearl River Delta region, innovation can be carried out on the system, such as breakthroughs in materials, energy coupling, and intelligent upgrading.

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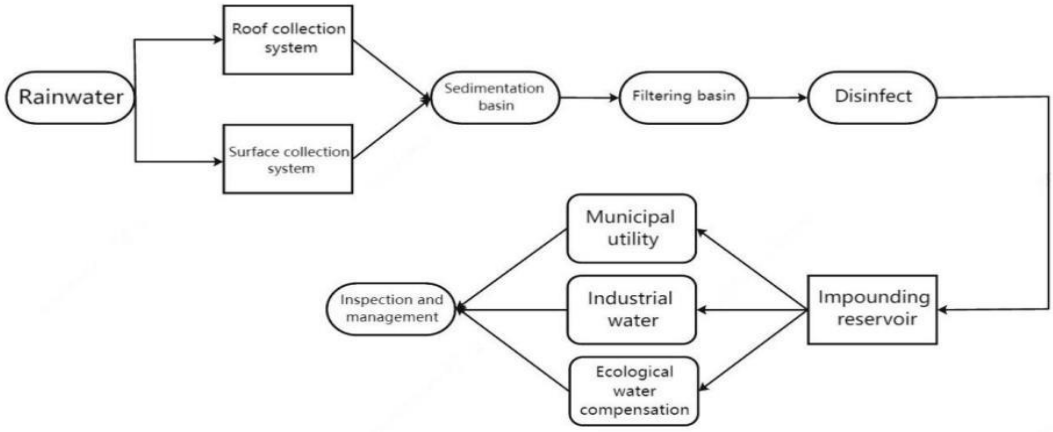

Figure 1: Urban rainwater resource utilization process

5. Case study of urban rainwater resource utilization in the pearl river basin

5.1. Case introduction

This study selects Shenzhen City of Guangdong Province as an application case for analysis. Located on the east bank of the Pearl River Estuary, Shenzhen has a typical subtropical monsoon climate with high temperatures and rainy summers and mild winters. From 2008 to 2017, the average annual precipitation in Shenzhen was 1863.9mm [12], and the rainfall in the rainy season accounted for 85% of the whole year. In summer, it was prone to short-term heavy precipitation with uneven distribution of precipitation time. Taking this example to analyze urban rainwater resource utilization in the Pearl River Basin is representative. As a window city of China's reform and opening up, Shenzhen has a high level of urbanization, a developed economy, and a permanent population of more than 20 million. Moreover, Shenzhen is still developing at a high speed. This means that water resources are one of the key factors limiting the sustainable development of the region. Due to local water scarcity, dense population and surging demand, Shenzhen has long faced challenges such as water shortage and water pollution. Shenzhen's terrain is mostly hilly, and near the sea, and there is no big river, so its ability to store rainwater is very limited, so the development of an urban rainwater resource utilization system is of great significance for Shenzhen.

The rainwater utilization system of Shenzhen City is analyzed, which includes a non-point source pollution control system, a rainwater infiltration system, and a collection and utilization system. As can be seen from Figure 2, rainwater from different ground flows into the rainwater collection network, and some rainwater penetrates and enters the non-point source for pollution control. The collected rainwater will be purified and then used with the infiltration of rainwater, and finally the water resources converted from the rainwater will be used for industry, landscape environment, urban utility, and supplementing and conserving groundwater and water sources.

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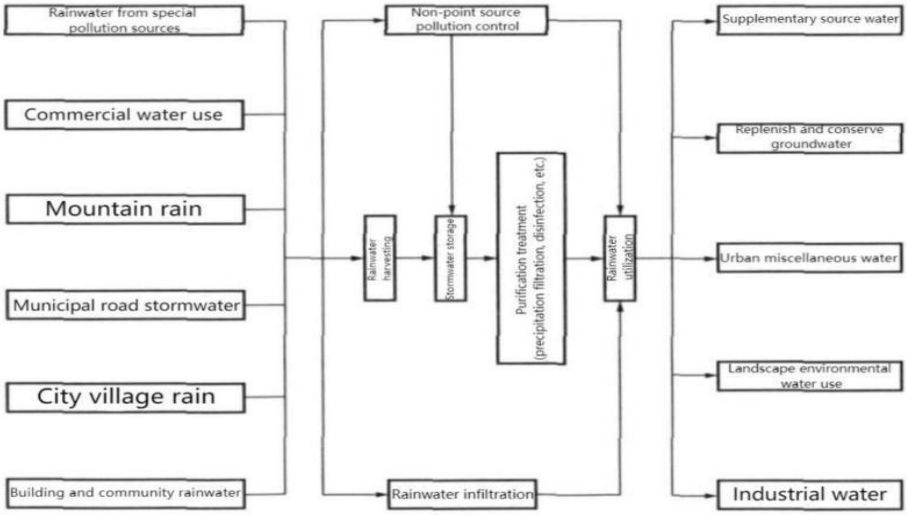

Figure 2: Shenzhen rainwater utilization system [12]

5.2. Effect evaluation

The system can effectively promote rainwater infiltration, raising the groundwater level in the eastern region by 0.5 to 1 meter. After the extension of the system, the incidence of waterlogging in the Shenzhen urban area can be reduced by 40% to 60%, and the peak runoff can be reduced. The utilization rate of rainwater has been improved, the annual water saving fee can reach 200 million yuan (calculated according to the Shenzhen water price of 5 yuan /m3), and the drainage cost can be reduced to save 150 million yuan in maintenance costs. After the scale of rainwater utilization system and the expansion of water resource storage system were increased, the drought resistance capacity of Shenzhen was enhanced, and the urban heat island effect was reduced (the surface temperature in the sponge area was estimated to decrease by 2℃ to 3℃).

5.3. Summary of experience

After years of exploration, the rainwater resource utilization model of Shenzhen has demonstrated significance. As a typical city of climate type in the Pearl River Basin, its experience is worthy of emulation by other cities in the Pearl River Basin. The establishment of the system requires careful planning and coordination. Shenzhen has clarified the mandatory requirements for rainwater utilization and implemented the accurate management of "one district, one policy". As a technology capital, Shenzhen combines technological innovation with rainwater utilization to greatly improve the utilization rate and environmental benefits of rainwater. The government has made great efforts to publicize rainwater utilization, and the whole people participate in the maintenance of rainwater utilization facilities. In addition, Shenzhen also has a good reference significance for the system to cope with heavy rainfall and typhoon resistance upgrades, and its measures to reduce flood peaks, non-point source pollution control and other objectives can be implemented in many cities in the Pearl River basin.

6. Conclusion

The population density is high in the Pearl River Basin, and the current situation of water resources is facing many challenges. The utilization of rainwater resources has great significance and considerable prospect. The utilization of urban rainwater resources in the Pearl River Basin needs to deal with the problem of uneven spatiotemporal distribution of precipitation in the Pearl River Basin,

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and it also needs to have the ability to resist typhoons and operate in the case of heavy rainfall. The technical system of urban rainwater resource utilization in the Pearl River Basin is mainly divided into three steps: collection, treatment and utilization. The system needs to be diversified to match the economic level and climate conditions of urban areas in the Pearl River Basin. Through the case analysis of Shenzhen rainwater utilization and its effect evaluation, it can enlighten the research of urban rainwater resource utilization in the whole Pearl River basin.

This study only focuses on the urban areas of the Pearl River Basin. In fact, there are not a few places in the Pearl River Basin with low urbanization levels, and it is difficult for them to implement the technical system of rainwater resource utilization discussed in this study. Due to the large scope of the Pearl River Basin and the variety of landforms covered, the rainwater utilization methods in different regions cannot be generalized. If the rainwater utilization systems of urban areas in the Pearl River Basin are to be established, more targeted studies are needed.

The overall trend of urban rainwater utilization in the Pearl River Basin can refer to the rainwater utilization model of Shenzhen, and design a rainwater resource utilization system that is more suitable for local climate characteristics, geographical conditions, economic level and water resource requirements. As the global climate warms, the frequency of extreme rainfall becomes higher and higher, and the future needs to develop its coping technology. The rainwater resource utilization system can also be combined with artificial intelligence to develop intelligent monitoring and other functions. With the implementation of the concept of sustainable development, new materials and processes can be tried in the future to use low-cost purification materials. In terms of policy and system, we can pilot the rainwater bank system, explore the financing model of "sponge city special debt", and formulate a tiered subsidy policy for rainwater reuse.

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