Study on Rainwater Utilization Engineering Mode in Northern Cities of China

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Abstract

Water resources in northern cities of China are in short supply, while rainwater resources are not made full use of. Using rainwater resources to solve the problem of water shortage in northern cities haven’t been put into practice. This paper took rainwater use in Handan City as an example, analyzed potential and economic benefits of city rainwater utilization, and discussed two project patterns of rainwater use which are suitable for climate characteristics and economic development of northern cities. The two project patterns are road rainwater collection and utilization, and roof rainwater collection and utilization. After analysis, these two kinds of engineering modes can largely solve the problem of water shortage in northern cities, and reduce the load of rainwater pipe network, which can make considerable economic benefits.

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1. Introduction

As everyone knows, China is in shortage of water resources, the amount of water resources is 2.81×1012 m³, ranking the sixth in the world, but per capita shares of water and average land shares of water are only the world’s 1 / 4 and 3 / 4 respectively[1]. According to the statistics, among over 700 cities in China, nearly 400 cities are short of water or even more seriously short of water, most of which are in the arid and semi-arid region of north and northwest of China. Scarcity of water resources in northern China is a big obstacle to the development of national economy. On the other hand, with the development of cities and the increase of impervious area, runoff coefficient is increasing and heavy rains

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converge quickly, then runoff volume increases exponentially. A large amount of rainwater resources flow away from urban sewer network, which not only wastes rainwater resources, but also adds load on urban drainage pipe network. According to the statistics, Beijing has an average of 700 million m$^3$ rainwater every year, and with the extension of the urban area, this value will continue to increase. How to use rainwater resources to fill the growing gaps of water utilization, especially "water shortage" problems in northern cities, is being taken more and more attention[2].

2. Potential analyses on city rainwater utilization

2.1. Domestic and foreign city rainwater utilization status

Foreign urban rainwater utilization started relatively early, and has formed the scale. Germany had introduced rainwater utilization facility standards since 1989 and had developed "the second generation" of rainwater utilization technologies by 1992. After nearly 10 years’ development and improvement, "the third generation" rainwater utilization technique appears, and its new standard is also being processed. In China, some large cities such as Beijing, Tianjin and Xi’an, are researching and applying rainfall flood utilization technology, but are in the demonstration stage and lack of systematicness, and the vast majority of urban rainfall flood utilization haven’t been put into practice [3].

2.2. Potential analysis on city rainwater utilization

Handan is a typical northern city, its downtown area is 104 km$^2$, and impervious area ratio is 0.8. According to average annual rainfall of 543.2 mm. Water productions are calculated as following.

$$ w = A \times \beta \times \alpha \times p $$

Where $A$ (m$^2$) is the city area; $p$ (m) is the average annual rainfall for many years; $\beta$ is impervious area ratio; $\alpha$ is runoff coefficient, and the runoff coefficient of impervious surfaces such as concrete and asphalt pavement is 0.9. Then the $w$ is 4067.48 ×104 m$^3$.

When the collection utilization rate is 50 percent, the collected rainwater is 20.3374 million m$^3$ per year. At the same time, the cost of rainwater utilization is low and the benefit is very prominent. According to statistics, the annual cost of per m$^3$ rainwater is less than 0.10 Yuan. If these rainwater are used for garden irrigating, the tap water of residents’ flushing and cleaning, the economic benefits will be very substantial. For example, the cost of water per m$^3$ is 1.8 Yuan in Handan, it will save 30.5061 million Yuan per year on urban greening and residents’ consumption if the market price of rainfall is 0.3 Yuan/ m$^3$.

Besides the considerable direct economic benefit, the indirect economic benefit is also substantial. Using rainwater resources locally can alleviate urban drainage pipe network load, reduce the government investment on large sewage treatment plants, sewerage pipelines and expansion of the flood relief facility.

3. City rainwater utilization engineering mode

At present, there are two main proven techniques about urban rainwater utilization, which are roof catchment and diversion of the road. The roof catchment is that using the roof of buildings to impound rain water, store on the ground or underground, filter and reverse osmosis filter, and using original pipe to convey the rainwater which is then used directly by the user. The diversion of the road is that dividing urban sewage pipes and rainwater collecting pipes. Rainwater collecting pipes are decentralized, reservoirs are placed under green spaces, by which water is collected on rainy days, and used on sunny days without treatment. Rainwater is slightly acidic natural water, and after neutralized by alkaline
substance in reservoir, it becomes soft water containing a small amount of mineral salt.

3.1. City road project pattern of rainwater use

Rainwater collection on motor vehicle road can be realized by the engineering model that building reservoir under greenbelt on separated road sections, as is shown in Fig 1.

Fig 1. City road pavement engineering of rainwater collection and utilization mode

In figure 1, L is the space between two reservoirs, D is road width, the direction of the arrow is the longitudinal gradient direction of the pavement, l means the length of a green belt, A is the space between two green belts, then:

\[ L = A + 1 \]  \hspace{1cm} (2)

Reservoir volume could be decided according to the characteristics of local hydro-meteorological situation, to make sure it can accommodate the produced rainfall of a certain frequency of designed storm, but the designed frequency storm must be suitable. If the produced rainfall is less, then the reservoir volume is not large to make full use of the rainfall on road; if the produced rainfall is more, the reservoir volume is too large, leading to a large cost and poor efficiency. Usually five-year or two-year designed storm is selected as the basis to decide the reservoir volume, then:

\[ V = P \times L \times D / 2 \times \alpha \]  \hspace{1cm} (3)

Where \( V \) (m\(^3\)) is reservoir volume; P (m) is the rainfall with the chosen design frequency; D (m) is the pavement width. \( \alpha \) is runoff coefficient and the runoff coefficient of impervious surfaces such as concrete and asphalt pavement is 0.9.

As the area of the side pavement is small and scattered, it has little sense to build reservoirs specially. Therefore, the engineering mode of laying permeable pavement brick on sidewalk can be used, so that rainwater enter into the ground to supplement groundwater directly.

Permeable paving brick is a mixture made of a particular gradation of aggregate, cement, water and strengthening agent, it is a concrete product made by specific technology, which contains a large percentage of interconnected porosity [4-5]. To meet the needs of control and utilization of rainwater in urban area, the strength of permeable pavement bricks are above 30 MPa, and its capabilities of water seepage can make sure the rainwater under 1mm/s can infiltrate into ground timely without surface ponding. The typical ground laying diagram is shown in Fig 2.

Fig 2. Typical permeable pavers paving diagram
In figure 2, coarse sand is used as filter layer raw material, mainly for filtering rainwater infiltration. Crushed rock layer play a role in storing rainwater for short-time, so as to prevent the ponding phenomenon caused by the delayed penetration.

3.2. Roof rainwater collection and utilization engineering mode

The collection and utilization of roof rainwater is much more complex than that of urban road rainwater, including rainwater collecting systems, filtration systems, storage systems, and recycling systems. Figure 3 is typical roof rainwater utilization engineering mode.

In figure 3, rain meet together through roof, then flows into gravel stone layer through downcomer, and then enters reservoir along lose pipelines after filter. Because the demands for water quality from roof rainwater users are stricter, the reservoir is divided into two layers. The rainfall from water pipes are directly accepted by the upper layer, then it is filtered again by the separated layer, which is a large pore concrete layer, and then flow into the lower reservoir. The collected rainwater is much cleaner at this time.

Roof rainwater collection and utilization engineering mode is widely used in community, shopping malls, office buildings, and so on. A building can be a unit for rainwater collection and utilization, a few buildings can also have their own collection systems but share a storage system at the same time.

4. Rainwater utilization engineering mode suitable for northern city and its economic analysis

The rainfall time of northern cities is not balanced, and is concentrated on several months in flood season with heavy rain in short time. And as far as economic development, most of the northern cities are medium-sized cities, the development of economy is backward relatively. So the most important problem for those northern cities to solve is: how to find the optimal model of urban rainwater utilization within the financial ability, maximize the use of urban rainwater, and produce greatest social and economic benefits.

4.1. Proper project pattern of rainwater use for Northern cities

Urban road and roof rainwater engineering mode is simple and the cost is low which can be used fully as available engineering mode of urban rainwater utilization in north China. Handan city is chosed as an example to analyse the economic efficiency.
4.2. City road project pattern of rainwater use in economic analysis

China Street in Handan city is chose as an example of which is about 16km. width of the street is 16m, greenbelt is 150m at length and space is 10m. The worst 24 hours (115mm) storm rainfall is chose as design standard.

According to the statistics data of Handan city Gardening Department, the total greening area of Handan is 2 million m$^2$. Annual irrigation water is about 2 m$^3$ for per 1 m$^2$ green belt so the total of annual irrigation water requirement is 4 million m$^3$. Each green belt needs 600 m$^3$ irrigation water every year, and every reservoir supplied 626 m$^3$ water per year, the water problem of the green belt can be solved completely, annual water conservation is up to 4 million m$^3$. Investment of water infrastructure for collecting 1 m$^3$ is 20 Yuan and construction funds that each reservoir need is 2,640 Yuan. Due to saving the money of irrigation water, costs can be recovered in three years, so its economic benefit is substantial.

According to market research, the prices of impervious glazed pottery and permeable pavement bricks are nearly same. Construction process is also similar. Now many cities like Beijing and Tianjin have exchanged permeable pavement bricks for glazed impervious bricks widely and pedestrian pavement in Handan city is still laying impervious glazed bricks which leads to excess water when the rainfall happened. It is recommended that intensify glazed impervious should be placed as permeable paving brick in the future.

4.3. Project economic analysis of roof rainwater collection and utilization mode

Handan hydroelectric biotope is located in southwest of Handan city of which residential area is 68,000 m$^2$, building area is 30,000 m$^2$, and resident population is more than 1000 people. If the area of roof rainwater can be used for 30,000 m$^3$, annual water storage capacity can be 17,000 m$^3$ according to annual precipitation of Handan 543.2 mm. According to the national urban water consumption quota (GB/T113-86), the annual water consumption of secondary cities households which have water supply and drainage equipment without bathing, is 40.15 m$^3$ per year. According to the above criteria, the community approximate yearly consuming water is 40200 m$^3$, and water consumption can be saved about 17,000 m$^3$, it accounted for about 40% of water consumption which may save 30,600 Yuan directly.

5. Conclusion

According to the above analysis, it is simple for the technology of road rainwater collection and utilization and the roof rainwater collection and utilization engineering mode which is also easy to implemented and the benefits are outstanding. It can be used as preferred engineering mode for utilization of urban rainwater in northern city which should be promoted vigorously.

References


