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Study on the theory and method of urban eco-environmental water demand and distribution

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ABSTRACT

Starting with the concept and connotation of urban eco-environmental water demand, this paper first analyzes the types and characteristics of urban eco-environmental water demand and explores the calculation methods of urban eco-environmental water demand from three aspects: domestic water demand, industrial water demand and natural eco-environmental water demand, then establishes a multi-objective allocation model based on ecological water resources system, and finally conducts an empirical study with Zhengzhou City as an example. It is predicted that the total urban eco-environmental water demand for the planning year (2020, 2025) will reach 1.032 billion m^3 and 1.171 billion m^3, respectively. The optimal allocation of water resources provides a theoretical basis for the rational use of water resources in Zhengzhou City.

Keywords: Urban ecological environment; Water demand theory; Optimal allocation; Water resources

1. Introduction

The study of eco-environmental water demand began in the 1940s. In order to avoid the degradation of river ecosystems, the United States Fish and Wildlife Service required that the minimum ecological flow of rivers should be maintained. Since the 1960s, many countries carried out researches on the basic flow of rivers and determined some relatively perfect calculation methods, but these studies have not linked water resources with the ecological environment [1,2]. Until the 1990s, with the implementation of the International Hydrological Programme and other major projects, researchers began to shift their research focus to the integrity of river ecosystems and even of off-river ecosystems [3–10]. China began the study of riverway and basin ecological water demand in late 1990s, but remarkable progress has been made so far. Chinese researchers have further explored the connotation of eco-environmental water demand and raised calculation methods of eco-environmental water demand under different conditions [11–15]. At present, the research on eco-environmental water demand at home and abroad mainly focuses on the rivers, lakes, wetlands and basins; and that on urban eco-environmental water demand is still in its infancy [16–21]. The city is a natural-artificial binary ecosystem that is different from the river basin ecosystem, easy to be affected by human intervention and subjective consciousness. The study of urban eco-environmental water demand relates to the potential of urban development and the quality of human life. Therefore, it is of great significance to study the theory and method of urban eco-environmental water demand and distribution.

2. Composition of urban eco-environmental water demand

2.1. Connotation of urban eco-environmental water demand

The urban eco-environmental water demand refers to the total amount of water resources required to maintain the

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normal material cycle, energy flow and information exchange in the urban ecological environment within a certain time and space. The eco-environmental water demand consists of ecological water demand and environmental water demand. For the natural environment, the ecological water demand refers to the amount of water needed to maintain the composition and structure of biological communities and the dynamic stability of biological habitats. The ecological water demand is not only related to the composition and structure of biological communities in the ecosystem but also related to climate, soil, vegetation, geology and other environmental conditions. The environmental water demand refers to the amount of water resources needed to improve water quality, ecology and environment. Therefore, the ecological water demand and the environmental water demand have overlapping parts, but their connotations are not the same.

2.2. Composition of urban eco-environmental water demand

Current studies on the urban eco-environmental water demand mainly concentrate on the water demand of the urban natural environment system, including greenbelt water demand, rivers & lakes, and groundwater recharge, leisure tourism water and sanitary water, without regard to the social and economic water consumption for living and production. However, from the definition of ecosystem, it is a natural body composed of biological communities and their habitats (water, light, soil, air, etc.) through energy flow and material cycle within a certain time and space. Greatly different from the river basin ecosystem, the urban ecosystem is a typical artificial ecosystem where mankind is the main biome. Human beings are both the constituent elements of the ecosystem and the reformers of the urban ecosystem [22]. Human beings can self-regulate and harmonize with the environment, but this regulation must abide by the laws of nature and use theories and methods of natural ecology; otherwise, they will destroy the entire system. Therefore, if we only consider the urban greening water and guarantee the water volume and quality of rivers and lakes, the water demand in these areas is only part of environmental water demand; however, in order to maintain the composition and structure of the urban ecosystem and the normal material cycle and energy flow, the water demand mainly refers to the production and living water demand, that is, ecological water demand. The natural environment is only a platform for the urban development, and the social economy is the lifeblood of the city. Therefore, the water demand of the urban ecological environment should include the sum of urban living water demand, industrial water demand and natural eco-environmental water demand [23]. The domestic and industrial water consumption is the main component of the urban eco-environmental water demand.

2.3. Multi-objective optimal allocation based on ecological water resources

The water resources allocation is the optimal distribution of limited water resources of different natures among basic sectors and different users in a specific basin or area by using engineering and non-engineering measures, to meet the multi-objective requirements and ultimately to achieve the sustainable use of water resources and support the goal of comprehensive, coordinated and sustainable development.

The water resources allocation is to enable the rational and full use of limited water resources and to provide a reliable water source for industries, living and ecology in an entire water supply area, so as to obtain the best overall benefits, including social, economic and eco-environmental benefits. Since the amount of water resources available for allocation in water-scarce areas is limited, it is difficult to meet the water demand of all sectors in these areas. Only when the basic needs of all sectors are met, economic goals, social goals and eco-environment development goals can be considered overall while adjusting the water supply and demand.

3. Calculation methods of urban eco-environmental water demand and water distribution model

3.1. Urban domestic water demand

The urban domestic water demand includes the residents' household water demand and the municipal public water demand. There are many factors affecting the urban domestic water demand, such as the city size, population, location, housing area, living standards, sanitary conditions, municipal public facilities and water resource conditions, among which the most important ones are the population and integrated water quota per capita. The urban domestic water demand is often calculated with the quota method, that is, the population in level year times the integrated water quota per capita. With the continuous expansion of the city size and the improvement of people's living standards, the demand for water in urban life will continue to increase.

3.2. Urban industrial water demand

The urban industrial water demand can be calculated with the method of water demand per 10,000 yuan output value, namely the 10,000 yuan output value in current year or in predicted level year times the water demand quota per 10,000 yuan industrial output value. This method is to estimate the industrial water consumption required for realization of an industrial output value target at present or in the future based on the status quo and historical change trends of the water withdrawal per 10,000 yuan industrial output value. Due to the large difference in the water withdrawal per 10,000 yuan output value among different industries or among different products and processes in the same industry, it is very difficult to determine the water demand of 10,000 yuan output value.

The industrial water demand can also be calculated with the demand growth trend analysis method. This method is used to calculate and estimate the industrial water demand for different level years according to the industrial water growth rate over the years. The industrial water demand is affected by the urban economic development level, city size, industrial structure and water resources reusing rate. These factors have certain change rules and trends, which can be reflected in the growth rate of industrial water consumption over the years. This is why the growth trend analysis method is more advantageous than others. However, it requires a series of historical data, for the accuracy of the calculation depends on the length and representativeness of the data series. With the continuous improvement of production processes and technologies, the water demand per 10,000 yuan output value will decrease, but as the scale of production expands, the urban industrial water demand will maintain a balanced or declining trend.

3.3. Urban natural eco-environmental water demand

The urban natural eco-environmental water demand W_c (m^3/a) includes urban green space ecosystem water demand, urban river, lake and wetland ecosystem water demand and sanitary water demand. The water demand of urban natural ecological environment is determined according to the urban development pattern, for the purpose of maintaining the ecological stability. With the continuous expansion of the city scale and the improvement of the landscaping level, the urban natural eco-environmental water consumption will increase in the future.

3.3.1. Greenbelt water demand

The calculation model of the urban greenbelt eco-environmental water demand is as follows:

$$W_{cg} = W_p + W_s \tag{1}$$

where W_{cg} is the urban greenbelt eco-environmental water demand; W_p is the urban greening plants water demand; W_s is the urban greenbelt soil water demand.

At present in China, the research on the relationship between vegetation water condition and growth status mainly focuses on crops, and there is no sufficient measured data to support the relationship between vegetation evapotranspiration and vegetation growth, soil moisture condition in urban green space systems. Here, the actual evapotranspiration follows the average actual evapotranspiration of vegetation in different cities, and the formula is as follows:

$$W_p = \left(1 + \frac{1}{99}\right) \times k \times \sum_{i=1}^{n} \beta_{li} \times \mathrm{ET}_{oi} \times A_{pi} \tag{2}$$

where W_p is the water demand of the urban greening plants; k is the unit conversion factor; β_{li} is the ratio of the actual evapotranspiration and the potential evapotranspiration of different vegetation; ET_{oi} is the potential evapotranspiration of different types of vegetation; A_{pi} is the cover area of different types of vegetation; n is the number of vegetation types; subscript i is the i type of vegetation. The time can be calculated with the unit of year, month, 10-d period, growth period, flood season and non-flood period according to needs.

The soil water demand refers to the water content that needs to be maintained stably in order to maintain the growth of vegetation. It is the water resources storage of the urban green space system, and provides necessary soil moisture for the growth and development of green vegetation. Due to the lack of relevant quantitative research data, the soil water demand can be calculated by selecting the average of urban soil moisture constant for a certain area. The calculation method is as follows:

$$W_s = k \times \alpha_s \times \sum_{i=1}^{n} H_{si} A_{si} \tag{3}$$

where W_s is the urban greenbelt soil water demand; k is the unit conversion factor; α_s is the ratio of the actual soil water content and the field water capacity under different grades; H_{si} is the effective soil thickness of different types of vegetation; A_{si} is the distribution area of the i-th soil.

According to "Urban Water Resources and Water Environment" [24], the water use in urban green space can be estimated simply by using 12 L of water per square meter of green space per month.

3.3.2. River & lake and wetland water demand

The calculation model of the urban river & lake and wetland eco-environmental water demand is as follows:

$$W_{cw} = W_w + W_u + \max\left(W_b, W_h, W_z\right) \tag{4}$$

where: W_{cw} is the urban river & lake and wetland eco-environmental water demand; W_w is the water demand of water surface evaporation; W_u is the water demand of water body leakage; W_b is the river base flow; W_h is the habitat water demand; W_z is the water demand of water body replacement.

3.3.2.1. Water demand of water surface evaporation

Water surface evaporation belongs to the water consumption. No matter it is a lake or a river, it must supplement this part of water, so as to ensure the water level basically unchanged under the water balance and ensure the existence of the urban wetland itself. The water demand of water surface evaporation in urban wetlands is calculated using the same method for the water demand of water surface evaporation in general wetlands:

$$W_h = E_{601} A_w \tag{5}$$

where W_h is the water demand of rivers, lakes and wetlands water surface evaporation; A_w is the wetland water surface area; E_{601} is the urban water surface evaporation measured with the E-601 evaporator.

3.3.2.2. Water demand of water body leakage

When there is water in rivers and lakes, causing higher water level and water pressure, and the groundwater level is low, it may lead to leakage and generate leakage loss. Leakage losses of lakes and reservoirs are related to the water surface area, water storage capacity and hydrogeological conditions. The water demand in the leakage of rivers, lakes and wetlands is calculated as follows:

$$W_u = kIB_uT \tag{6}$$

where W_u is the water demand of rivers, lakes and wetlands leakage; k is the unit conversion factor; I is the hydraulic slope; B_u is the area of the leakage section; T is the length of calculation time.

3.3.2.3. Ecological base flow

For urban rivers, the ecological base flow is mainly reflected in maintaining the river's existence, flow velocity and flow state. The calculation formula of the ecological base flow for urban rivers (especially artificial rivers) is given as follows based on the main ecological and environmental functions of urban rivers, as well as the water surface area, average section width and depth, average flow velocity and seasonal changes of urban rivers:

$$W_b = kVB_bT \tag{7}$$

where W_b is the ecological base flow of the river; k is the unit conversion factor; V is the average flow velocity of the river section, which can be obtained from the measured data or by using the hydraulic formula; B_b is the discharge section area; T is the time, with the unit selected from year, flood period, non-flood period, month, 10-d period and day according to the accuracy.

The flow rate at the river section can be calculated using a relatively simple Chezy formula, as shown below:

$$V = \frac{1}{nR^{2/3}}\sqrt{i} \tag{8}$$

where V is the average flow velocity of the river section; R is the hydraulic radius; n is the manning bed roughness coefficient; i is the longitudinal slope of the river.

3.3.2.4. Habitat water demand (W_h)

In order to maintain the normal ecological and environmental functions of rivers, lakes and wetlands, it is necessary to ensure the annual quantity of water in urban wetlands under the allowable range of water level changes. The said water quantity is a prerequisite for urban wetlands to function as habitats and landscapes and to exist itself, and it is also an important component of urban wetland eco-environmental water demand. The habitat water demand can be calculated with the following formula:

$$W_b = \varepsilon A_h H_h \tag{9}$$

where W_h is the water demand of river, lake and wetland habitats; ε is the proportion of wetland water surface area to the total wetland area; A_h is the urban water surface area; H_h is the average water depth of different grades of wetlands.

3.3.2.5. Water demand of water body replacement (W_z)

When rivers, lakes and wetlands cannot purify foreign pollutants themselves, causing serious deterioration of the water quality, the artificial water exchange provides a solution, the essence of which is to promote the flow of water body. The volume and period of water exchange are generally planned by relevant departments to achieve the best results. The water exchange should be performed together with the desilting and dredging. The calculation formula for the water demand of water body replacement in rivers and lakes is as follows:

$$W_z = A_w H_w T_z \tag{10}$$

where W_z is the water demand of urban rivers and lakes water replacement; A_w is the water surface area; H_w is the average depth of rivers, lakes and wetlands of different levels; T_z is the period of exchanging water.

According to the calculation method of water demand of urban green space, urban rivers, lakes and wetlands ecological environment, the calculation model for the urban environmental water demand can be obtained as follows:

$$W_C = W_{Cg} + W_{Cw} \tag{11}$$

3.4. Multi-objective optimal allocation model of urban water resources system

3.4.1. Optimization goals

The general objective or the highest-level objective of water resources system optimization is to achieve a reasonable allocation of water resources and to support the overall coordinated and sustainable development of society, economy and environment [25]. Therefore, the overall goal for optimal allocation of urban water resources should include economic goal, social goal and ecological environment goal, which requires a multi-objective optimization model, that is, the economic benefit target is represented by the largest total economic benefits generated by water consumption in different industries in each level year, the water supply cost target is represented by the minimum total water supply cost in each level year, the ecological target is represented by the minimum water deficit in water systems in each level year, and the social target is represented by the minimum water shortage of each user in each level year.

3.4.2. Objective function

- Economic benefit target: the maximum economic benefits generated in each level year by water consumption in different industries in the sub-area

$$\max f(x) = \sum_{j=1}^{J}\sum_{i=1}^{I} b_{ij}x_{ij} \tag{12}$$

where x_{ij} - the amount (10,000 m^3) of water supplied by the water source i to user j; b_{ij} - the benefit coefficient (yuan/m^3) for unit water supply from the water source i to user j.

- Water supply cost target: the minimum cost generated in each level year by water supply in different industries in the sub-area

$$\min f(x) = \sum_{j=1}^{J}\sum_{i=1}^{I} c_{ij}x_{ij} \tag{13}$$

where x_{ij} - the amount (10,000 m^3) of water supplied by the water source i to user j; c_{ij} - the cost coefficient (yuan/m^3) for unit water supply from the water source i to user j.

- Ecological target: the minimum water shortage in various water systems in all sub-areas at each level year

$$\min f\left(sq\right)=\sum_{h=1}^{H}\left(\sum_{i=1}^{I}x_i-q_h\right) \tag{14}$$

where x_{ih} - the quantity (10,000 m^3) of water supplied from the water source i to riverway h; H - the number of rivers and lakes; q_h - the water demand of riverway h. The other symbols have the same meaning as above.

- Social target: the minimum water deficit for each user at each level year

$$\min f\left(tq\right)=\sum_{j=1}^{J}\left(\sum_{i=1}^{I}x_{ij}-q_j\right) \tag{15}$$

where x_{ih} - the quantity (10,000 m^3) of water supplied from the water source i to riverway h; q_j - the water demand of user j.

3.4.3. Constraints

Various constraints should be considered in the process of optimization calculation. This study mainly takes the following constraints into account:

3.4.3.1. Water supply constraints

The water supply constraints are determined according to different water supply sources. The water sources are, respectively, shallow groundwater, deep groundwater, river network water, reservoir water, reclaimed water, and cited water from the Yellow River and the middle line of South-to-North Water Transfer Project, which can be classified into allocable water sources and independent water sources according to the allocation of different water sources in the entire area. The allocable water sources include the reservoir water, water from the middle line of the South-to-North Water Transfer Project and water from the Yellow River, and the independent water sources include shallow groundwater, deep groundwater, river network water and reclaimed water. The allocable water sources can be adjusted in all sub-areas, while the independent water sources can only be adjusted among users in the area.

- Constrains on available water supply by reservoir water. The available water supply of reservoirs is related to the storage, diversion and extraction scale, capacity and management measures of the reservoir. During the calculation period, the quantity of water distributed to different users from different reservoirs cannot exceed the total quantity of water supplied by the reservoir. It can be expressed as:

$$\sum_{j=1}^{J}x_{lj}\leq W_l \tag{16}$$

where x_{lj} - the amount of water supplied by reservoir l to user j; W_l - the total amount (10,000 m^3/a) of water supplied by reservoir l.

- Constrains on available water supply by water from the middle line of the South-to-North Water Transfer Project: the total water demand cannot exceed the available water supply by the water from the middle line of the South-to-North Water Transfer Project.

$$\sum_{j=1}^{J}x_j^k\leq W \tag{17}$$

where x_j - the amount of water supplied by the middle line of the South-to-North Water Transfer Project to user j; W - the total amount (10,000 m^3/a) of water supplied by the middle line of the South-to-North Water Transfer Project.

- Constrains on water from the Yellow River: the total amount of water diverted from the Yellow River cannot exceed the total water diversion index.

$$\sum_{j=1}^{J}x_{hj}\leq W_h \tag{18}$$

where x_{hj} - the amount of water supplied by water from the Yellow River to user j; W_h - the total amount (10,000 m^3/a) of water supplied by the water from the Yellow River.

- Constrains on available water supply by independent water sources: the constrains on available water supply are basically the same for independent water sources. Take the shallow groundwater as an example.

Constrains on available water supply by the shallow groundwater: the total amount of shallow groundwater used by different users in different sub-areas cannot exceed the amount of shallow groundwater available for each level year.

$$\sum_{j=1}^{J}x_{qj}\leq W_q \tag{19}$$

where x_{qj} - the amount (10,000 m^3) of water supplied by the shallow groundwater to user j; W_q - the total amount (10,000 m^3/a) of water supplied by the shallow groundwater.

Constraints on over-exploitation of groundwater: the total amount of shallow groundwater over-exploited by different users cannot exceed the shallow groundwater volume allowed for over-exploitation at each level year.

$$\sum_{j=1}^{J}c_j\leq C \tag{20}$$

where c_j - the amount (10,000 m^3) of over-exploited water supplied by the shallow groundwater to user j; C - the permissible amount (10,000 m^3/a) of over-exploited water from the shallow groundwater.

3.4.3.2. Water demand constraints

The water demand constraints are determined according to the nature of water users. The water users include urban life, general industry, power industry, construction industry, tertiary industry, urban green space, rivers and lakes; the water demand constraints mean that the water supply to different users cannot exceed the user's water demand. For the water demand of urban life, it is necessary to meet the minimum water demand for daily life before the optimal allocation. Input and output constraints should be composed on all sectors of the national economy. The demand for water in each industry (or category) also depends on the average water saving level and water consumption level (unit consumption). Take the constraints on the general industrial water demand as an example to illustrate the water demand constraints.

Constraints on the general industrial water demand: The amount of water supplied by each water source to the general industry should not exceed the water demand of the general industry for that level year.

$$\sum_{i=1}^{I} x_i \leq S \tag{21}$$

where x_i - the amount (10,000 m^3) of water supplied by water source i to general industries; S - the total water demand (10,000 m^3/a) of general industries.

Other constraints that need to be considered include eco-environmental constraints namely water use in urban parks, green areas and landscapes, water demand of natural vegetation and shelterbelts and for maintenance of ecological functions of lakes and wetlands; reservoir level and capacity constraints; water supply capacity constraints for water transport and distribution engineering.

4. Application example

4.1. Zhengzhou overview

Zhengzhou City is located in the north of central Henan Province and falls under the north temperate monsoon climate. The annual average rainfall in Zhengzhou City is 640.9 mm. Influenced by various factors such as topography and geomorphology of underlying surface, the temporal and spatial distribution of precipitation is uneven, which is reflected in rainy summer, less rain and snow in winter, and about 60% of annual rainfall in the 3 months from July to September in flood season; with large inter-annual changes, the city's variation coefficient of average annual precipitation is within 0.24~0.30. The annual water surface evaporation is between 1,697 and 1,044 mm with an average of 1,221 mm, and the drought coefficient (ratio of annual evaporation capacity to annual precipitation) is greater than 1.0. For many years in Zhengzhou, the average water production (the ability to convert precipitation into water resources) coefficient is 0.28, and the average total water resources are about 597.3 million m^3 (the Yellow River's transit water volume has not been calculated). The water resources per capita amount to 212 m^3, accounting for about 1/2 of the province's total water resources per capita and 1/10 of the country's per capita water resources. Seen from the distribution of precipitation and per capita water resources, Zhengzhou City is short in water resources.

In the south of the Yellow River, Zhengzhou has Kuhe River, Jialu River, Jialu Branch River, Suoxu River, Jinshui River, Dongfeng Canal, Xiong'er River, Qili River and Chaohe River running through, among which Kuhe River belongs to the Yellow River system and other rivers belong to the Jialu River system, a secondary tributary of the Huaihe River. According to the ecological water system plan, Zhengzhou will focus on building 12 rivers and canals (6 vertical and 6 horizontal), 12 reservoirs (7 large and 5 small), 3 lakes and 2 wetlands. At the end of 2015, the total population of Zhengzhou City was 9.569 million, up 2% over the previous year; the GDP was 731.52 billion yuan, up 10.1% over the previous year; the per capita GDP was 77,217 yuan, up 7.9% over the previous year [26].

4.2. Calculation of Zhengzhou urban eco-environmental water demand

The eco-environmental water demand (Table 1) of Zhengzhou City for the planning year can be calculated with the above method. The water demand of rivers, lakes and wetlands is the amount of water required to maintain the ecological water system of Zhengzhou City, and it depends on the leakage and evaporation of the rivers and lakes. According to Zhengzhou's Ecological Water System Upgrading Plan, the water demand of rivers and lakes is calculated using the replenishment method: rivers are recharged by 100% of the river volume once every 20 d in the winter, every 15 d in the spring and autumn, and every 10 d in the summer (non-flood season) or every 30 d in the summer (flood season), 23 times in total in a year; and lakes are recharged six times a year, with 50% of the lake volume for each time. Based on this, we can obtain the predictions of water demand of rivers and lakes in Zhengzhou in 2020 and 2025, which are 1.032 billion m^3 and 1.172 billion m^3, respectively. This further evidences that the city is a typical artificial ecosystem, and the urban eco-environmental water demand may gradually rise with the urban development, population increase, industrial growth, greening and rivers and lakes expansion.

4.3. Optimal allocation of urban water resources based on the ecology

Likewise, the water resources allocation in Zhengzhou City should also be adjusted from the water demand and water supply. The optimal allocation needs to address the following problems: how to properly distribute different water sources to different users, how to rationally allocate the water that can be allocated in the city to various water

Table 1
Eco-environmental water demand of Zhengzhou City for the planning year, unit 10^4 m^3

Year	2020	2025
Domestic water demand	51,305	60,784
Industrial water demand	17,292	19,619
Greenbelt water demand	4,283	5,337
River and lake and wetland water demand	30,363	31,418
Total	103,243	117,158

Table 2
Optimal allocation of water resources in Zhengzhou City for the planning year, unit 10^4 m^3

Category of water sources	Category of water demand					
	Domestic water demand		Industrial water demand		Natural eco-environmental water demand	
	2020	2025	2020	2025	2020	2025
Water from the South-to-North Water Transfer Project	49,000	49,000	0	0	0	0
Groundwater near the Yellow River	2,305	4,415	0	0	0	0
Surface water in urban areas	0	0	0	0	476	476
Groundwater in urban areas	0	5,840	173	0	0	0
Surface water from the Yellow River	0	1,529	4,819	7,319	26,541	15,364
Reclaimed water	0	0	12,300	12,300	7,629	20,915
Total	51,305	60,784	17,292	19,619	34,646	36,755

use departments, and how to reasonably assign the water sources within each water use department to different users.

From the analysis of optimal allocation results (Table 2) of water, resources for the planning year obtained with the said method according to the total water supply (Table 3) available in Zhengzhou City, we can conclude that: with the middle line of the South-to-North Water Transfer Project into operation, Zhengzhou's domestic water will be mainly from the water from the South-to-North Water Transfer Project and supplemented by the groundwater near the Yellow River in 2020; while in 2025, along with the expansion of the economic and social scale, the city's domestic water will also need to be supplemented by the surface water from the Yellow River, in addition to groundwater near the Yellow River and groundwater in urban areas, and the industrial water will be mainly supplied by the reclaimed water and part of surface water from the Yellow River and groundwater in urban areas. In 2020, the urban natural eco-environmental water will mainly depend on the surface water from the Yellow River, supplemented by the reclaimed water; while in 2025, as the amount of reclaimed water increases, the natural eco-environmental water will mainly depend on the reclaimed water, supplemented by the surface water from the Yellow River.

Based on the analysis of balance between water resources supply and demand in Zhengzhou for the planning year, the water resource conditions in Zhengzhou City will be greatly improved with the middle line of the South-to-North Water Transfer Project put into operation, the water demand of the city's ecological environment will be guaranteed, and the city's water-based development goal of clear water, health and safety, eco-environment protection and man–water harmony will be achieved, but the remaining water rate in the planning year 2020 and 2025 is declining. With the construction of the Zhengzhou national central city, the city's economy and society will see a leap-forward development, but it may face the challenge of water shortage again in the future. Therefore, on the one hand, we must strengthen the people's awareness of saving water and cherishing water resources and build a water-saving society; on the other hand, we need to demonstrate the new water sources in advance and speed up the implementation of the "West-to-East Water Diversion Project" of Luhun Reservoir.

Table 3
Total water supply available in Zhengzhou City for the planning year, unit 10^4 m^3

Year	2020	2025
Water from the South-to-North Water Transfer Project	49,000	49,000
Surface water from the Yellow River	31,360	31,360
Groundwater near the Yellow River	4,415	4,415
Groundwater in urban areas	5,840	5,840
Surface water in urban areas (P = 95%)	476	476
Reclaimed water	19,929	33,215
Total	111,020	124,306

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