On the Planning Methods for Sustainable and Comprehensive Utilization of Water Resources in the Green Ecological Urban Area: An Empirical Study on a Green Ecological Urban Area in Jiangsu, China

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Abstract. The study on comprehensive utilization planning of urban water resources for sustainable development is one of the important contents of urban green ecological adaptive development and construction. The sustainable water system in the green ecological urban area has to make systematic analysis and overall planning of various elements of urban water system. From the perspective of urban water supply, water use, drainage, flood control and drainage and comprehensive utilization of water resources that require organic coordination, this paper forms systematic planning methods combining the computing method for water environmental carrying capacity with the construction of a capacity control model for water resources in the green ecological urban area. With the proposed strategic measures for the sustainable and comprehensive utilization of water resources in the green ecological urban area, this paper aims to achieve high quality and efficient water ecology, water security and water environment and eventually realize the organic coordination of nature and artificial system as well as the harmonious development between man and nature.

1. Introduction
Ecological environment is an important factor for green ecological adaptive city development. As a key controlled factor for ecological environment, water resources play an important role in the harmonious development of the combined system of society, economy and ecology of the entire city. Faced with great pressure from urbanization, water resources shortage, poor sewage treatment capacity and urban rainfall flood become major problems in the use of water resources. To integrate nature and artificial water system and realize the sustainable development of water resources, the principle of “water-saving and emission reduction” and “ecological cycle”, namely “water resource saving, efficient utilization, ecological cycle and water environment protection” should be followed, which is also a major challenge for water system construction under the strategy of green ecologically adaptive city development[1-2].

Water resources-related contents in traditional city planning mainly include urban water taking, water supply, water use, drainage and drainage network planning as well as planning and construction of “urban water supply plant and sewage treatment plant” and seldom involve level and efficiency of urban water use such as water conservation, energy conservation in water use, regeneration and reuse.
of water, quality of water resources and status of water ecology. It is difficult for traditional city planning to be in harmony with the goal of comprehensive utilization of water resources in the sustainable development concept of a green ecological adaptive city[3].

Hence, traditional city planning demands improvement. A multi-level system for comprehensive utilization of water resources has to be built based on guaranteeing water security and water ecology to make sure that the comprehensive sustainable utilization of water resources is in line with the city’s goal of achieving green ecological adaptive development.

2. Research Methods

2.1. Objectives and Principles
The comprehensive planning and management of water resources is an important content of green ecological adaptive development. It carries out planning and management of water supply, sewage treatment, water recycling and rainfall flood in accordance with the concept of green ecological cycle to realize the goal of lowering water resource demand, consumption and circulation utilization of energy resources and reducing emission. Therefore, the planning and construction of a sustainable water system attaches importance to respect and utilization of features of local natural environment, reasonable distribution, development and utilization, scheduling and protection of water resources with planning and construction management means and proper technical measures and optimization of a water supply and drainage system that fits with the urban development level. At the same time, gradually improve the construction of rainwater and sewage utilization facilities, improve the utilization of non-traditional water resources and relieve the pressure of urban water shortage from the perspective of reutilization. Urban development has to reduce urban rainfall runoff based on infiltration in line with the philosophy of “low impact development (LID)”, improve engineering systems and construct waterfront facilities according to the urban environment, and promote the harmonious coexistence of urban construction and nature.

Specific planning and construction principles are as follows.

a) Stick to the principle of “adjusting measures to local conditions and making overall consideration”. The sustainable water system has optimized, deepened and supplemented the overall regional planning and has to reflect regional suitability and technical feasibility and technical advancement as well.

b) Follow the water use principle of “high-quality water for high-efficient use and low-quality water for low-efficient use” to strengthen the sustainable utilization of water resources.

c) Enhance the study on mode and technology of “low impact development” and construct an economical, applicable and efficient technical system from multiple levels and dimensions.

2.2. The Carrying Capacity of Water Environment in the Green Ecological Urban Area
The carrying capacity of water environment is the foundation for study on water environmental capacity of green ecological urban area. Carrying capacity of water environment in the green ecological urban area means that the water can be sustainably used and maintain its good ecological system with the overall planning of green ecological urban area. It is the maximum capacity for holding sewage and pollutants as it meets the requirement of green ecological index. The water resource capacity can be confirmed after the water resource carrying capacity of green ecological urban area is determined. Therefore, the key link for sustainable planning of water resources lies in determining a water resource capacity control model for green ecological urban area.

The pollution load for abatement is determined by predicting pollution load and making comparison of predicted value of pollution load and water resource capacity during the planning process of water resources in the green ecological urban area. The pollution load for abatement in various water use blocks is distributed in accordance with fair, scientific and reasonable distribution principles.
In the aspect of technology, measures such as sewage reclamation and reuse, recycled water utilization and water-saving equipment system are able to effectively improve urban available water quantity, lower polluted water quantity and reduce pollution load. Furthermore, measures such as construction of permeable ground, ecological green space, ecological wetland and rainwater utilization can also help reduce the utilization of water resources and abate pollution load.

2.3. Capacity Control Model for Water Resources in the Green Ecological Urban Area

2.3.1. Water resource capacity \( G \).

When the water quality standard in a certain block within the planning area meets the planning objective of water resources in the green ecological urban area, if \( G \) is the water resource capacity in line with this area’s water quality standard, the calculation formula of \( G \) is as follows.

\[
G = 86.4[(Q_0 + q)C_s - e^{-\frac{kx}{86400u}} - C_0Q_0] \tag{1}
\]

In the formula,
- \( Q_0 \) — upstream water inflow, m\(^3\)/s
- \( q \) — pollution discharge flow, m\(^3\)/s
- \( C_s \) — control standard concentration of pollutant, mg/l
- \( u \) — average river flow rate, m/s
- \( x \) — channel length, m
- \( k \) — comprehensive degradation coefficient of pollutant, d\(^{-1}\)
- \( C_0 \) — environmental original value of pollutant, mg/l.

The water resource capacity of a certain block is calculated above. When there are multiple blocks in the green ecological urban area and each block has river channels, the water resource capacity of green ecological urban area is the superposition of water resource capacity of all channels as follows.

\[
aG = \sum G_i \tag{2}
\]

In the formula:
- \( aG \) — total amount of water resources in the green ecological urban area, t/a
- \( iG \) — water resource capacity of a certain river channel, t/a.

2.3.2. Distribution of total amount of water resources.

After the total amount of water resources in the green ecological urban area is determined, the allowable discharge rate of various blocks along the river channel should be fairly distributed following the principle of equitable distribution of water resource capacity. It is distributed by the ratio of the load at the discharge point of pollution source in the pollution load that the entire river channel can bear, shown as follows.

\[
G_{in} = \frac{G_i}{l_{ip} + l_{in}} \tag{3}
\]

In the formula,
- \( G_{in} \) — allowable discharge amount of non-point source pollution load of the i channel in the green ecological urban area, t/a
- \( G_i \) — water resource capacity of a river channel, t/a
- \( l_{in} \) — pollution load generated by the i channel section, t/d
- \( l_{ip} \) — pollution load of a certain point generated by the i channel, t/d.

2.3.3. Pollution load abatement.
When the comparison is made between water demand $W$ and water resource capacity $G_a$ in the green ecological urban area, the pollution load should be abated if the water demand exceeds water resource capacity. Abatement measures are also important planning contents of green ecological urban area, mainly including rational planning of regional water resource consumption (water demand) and sewage regeneration and reuse. Water consumption index should be rationally determined according to different land use functions of the green ecological urban area and the Code for Urban Water Supply Engineering Planning (GB50282-2016) to prevent excessive water consumption index[5].

2.4. Water Resource Planning Process of the Green Ecological Urban Area

The planning process can be established based on the water resource planning model of the green ecological urban area. First, set planning goals, which mainly include standard level for water quality in the planning area, water supply infrastructure in the planning area and water-saving percentage, etc. The water resource capacity of the green ecological urban area can be confirmed based on planning goals and distribution of water resource capacity determined in line with the equity principle. Select an index system in the ecological area and determine index systems such as water demand index, municipal water supply amount and sewage treatment index on the basis of planning goals. A contrastive analysis should be made between water demand and water resource capacity according to the index system. Water resource control measures in the ecological area are planned based on the confirmed pollution load abatement amount.

Give feedback to adjustable index system according to planning goals and adjust water resource control measures, make systematic optimization analysis and eventually achieve fair, reasonable and scientific planning based on repeated calculation and planning analysis.

2.5. Empirical Analysis

An application analysis of planning model is conducted by taking water resource planning of a certain green ecological urban area on Taihu Lake Plain in the Yangtze River Delta as an example.

2.5.1. Planning project introduction.

This green ecological urban area is located in the northwestern Taihu Lake Plain in the Yangtze River Delta with an area of 220km$^2$. The river channel in the green ecological planning area is 2,100km long, and the water area accounts for 27.4% of the total area, thus it is a typical “water town in the Yangtze River Delta”. The surface drainage has lakes and river channels. There are 5 regional cross-district channels as stage-1 river channel, 14 urban cross-section main river channels as stage-2 channels and 38 internal channels in various drainage sections as stage-3 channels.

2.5.2. Planning objective and index system.

The water supply capacity of urban water plant has a 10% surplus reserve amount after it meets the maximum daily planning water consumption, and the emergency water supply amount is no less than 50% of the ordinary water supply amount. The concentrated urban sewage treatment rate reaches 100%, the whole area is equal or greater than 90%, and the utilization rate of non-traditional water source is equal or greater than 30%. All river channels meet corresponding criteria of water environmental functional zones and clear all poor V-category water quality in recent days.

The planning index system is built from water environmental quality, water resource utilization, water pollution control and water resource management and sets indexes from water saving, water supply from multiple water sources, dual water supply, sewage reclamation and reuse, ecological rainfall flood utilization and so forth.

2.5.3. Total amount of water resources in the planning area.

Located in the water network area of Taihu Lake in the lower reaches of Yangtze River, rivers in the green ecological planning area are horizontally and vertically distributed. The water area is about 339,300 acres, including 106,900 acres of river channels and 232,400 acres of lakes.
It can be learned that the multi-year average annual water resource quantity of the entire area is 240,000 m$^3$ according to the survey result and calculation method of total amount of water resources, including 2.36 billion m$^3$ of average surface water resource quantity and 28 million m$^3$ of average ground water resource quantity. The average water resource occupancy volume is 1,529 m$^3$ per person.

2.5.4. Water demand of the ecological area.
A future water use model in the planning area can be estimated and built based on the water use structure and water consumption in a base year in the area, among which the agricultural water consumption accounts for the largest number, about 62% of the total water consumption, followed by industrial water consumption and households' domestic water consumption, accounting for 23% and 10% respectively. The proportions of urban public water consumption in cities and ecological environmental water consumption are 4.03% and 0.61% respectively.

According to short and long-term planning population and per capital water consumption index, it can be estimated that the short and long-term maximum daily water consumption quantities in the planning area are 450,000 m$^3$ and 523,000 m$^3$ respectively, and the annual water consumption amounts are 164.25 million m$^3$ and 190.71 million m$^3$. Short and long-term daily converted water consumption can be obtained after getting water demand in various fields based on the water demand ratio in life, industry, urban public and ecological environment estimated by the model (Table 1).

Table 1. Water demand and proportion in different fields of the adjusted ecological area.

| Level year | Life (ten thousand m$^3$/a) | Industry (ten thousand m$^3$/a) | Urban public(ten thousand m$^3$/a) | Ecological environment(ten thousand m$^3$/a) | Total (ten thousand m$^3$/a) | Converted daily water consumption(ten thousand m$^3$/d) |
|-----------|-----------------|----------------------|-------------------------------|----------------------------------------|-----------------------------|-------------------------------------|
| Short-term | 8952            | 10240                | 2484                         | 5634                                   | 27309                       | 75                                   |
|            | 32.8%           | 37.5%                | 9.1%                         | 20.6%                                  | 100.0%                      |                                     |
| Long-term  | 10452           | 12878                | 3956                         | 5701                                   | 32986                       | 90                                   |
|            | 31.7%           | 39.0%                | 12.0%                        | 17.3%                                  | 100.0%                      |                                     |

2.5.5. Water balance analysis.
It can be learned from water supply planning in the planning area that the water supply objective is to achieve an emergency water supply amount no less than 50% of the ordinary water supply amount and the water supply capacity of urban water plant possessing an extra 10%-15% of reserve amount (use 10% for calculation) as it satisfies the maximum daily planning water consumption. The water balance analysis is shown as Table 2.

Table 2. Water balance analysis.

| Water plant | Maximum water supply scale(ten thousand m$^3$/d) | Actual water supply(ten thousand m$^3$/d) | Maximum water demand in the ecological area (ten thousand m$^3$/d) | Surplus water volume (ten thousand m$^3$/d) |
|-------------|-----------------------------------------------|------------------------------------------|---------------------------------------------------------------|------------------------------------------|
|             | Short-term                                   | Long-term                                  | Short-term                                      | Long-term                                |
| Water plant 1 | 30                                             | 57                                         | 75+7.5=82.5                                     | -25.5                                    |
| Water plant 2 | 30                                             |                                            | 90+9=99                                        | -51.9                                    |
| Water plant 3 | 10                                             |                                            |                                               |                                          |

It can be seen that there is a gap in water supply amount in the planning area from above-mentioned analysis. Three effective solutions can be adopted, throttling, expansion of water plant and supplementing by unconventional water sources.

2.5.6. Planning of water resource control measures.
According to calculation and analysis above, water resource green strategies in the planning area involve water saving and water supply in five aspects, a) water saving: reduce water demand of running water, b) improve the utilization rate of non-traditional water sources, c) sewage: discharge reduction, improve concentrated treatment rate, d) rain water: ecological rainfall flood, high permeability and low impact, e) water quality: maintenance and improvement, ecological and livable.

3. Results
The emphasis and difficulty of comprehensive utilization strategies for water resources in the green ecological urban area is the construction of two major projects, non-traditional water source utilization and reclaimed water reuse, and scientific planning of municipal sewage treatment for reuse system and construction water reuse system. The project will focus on conducting reuse of reclaimed water from sewage treatment plant and ecological utilization of rainwater in large scale and improving the sewage treatment system.

4. Discussion
Based on the planning model and examples, the sustainable and comprehensive utilization planning of water resources in the green ecological urban area first determines the planning index system by dismantling the general planning objective and then plans total amount of water resources and water demand in the planning area. From the water balance analysis, it can estimate the surplus or deficit of water supply amount and eventually obtain strategic planning direction and technical measures for the sustainable and comprehensive utilization of water resources.

5. Conclusion
The sustainable comprehensive utilization system for urban water resources is a complex system involving economy, society and all kinds of environmental elements by taking water as a focus and city as a research category. Extensively speaking, it covers water environment, water security, water landscape, water culture and all other urban water-related aspects, including water resources, water volume, development, utilization and allocation of water resources, urban water supply guarantee, pollution source discharge, water environmental protection and control, rainwater and flood control and drainage measures, humanity history and water culture. It also involves water area and living comfort related to human settlement, water pollution and water body remediation, water landscape and human-water attachment and ecological water demand.

The urban water system is not a simple superposition of subsystems, and the sustainable development of urban water system should be monitored, managed, evaluated and optimized dynamically from leading water resources into city to the end and achieve water resource saving, high-efficient utilization, environmental pollution abatement and rational planning from strategies.

Hence, “water resource saving, efficient utilization and water environmental protection” should be conducted and a complete urban sustainable water system studied and perfected, so as to implement sustainable development objectives of water resources.

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