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Construction of water ecological infrastructure in the process of urbanization

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ABSTRACT

In order to study the corresponding impact of aquatic ecological infrastructure on the process of urbanization, and avoid the current problems of unreasonable resource development, land waste, and deterioration of the ecological environment, a research on the construction of aquatic ecological infrastructure in the process of urbanization is proposed. Based on the geographic information system technology environment, simulate and analyze the regional water ecological process, construct the landscape security pattern of water ecological management, plan and construct the type, scale, layout and structure of water ecological infrastructure, form a complete network system of water ecological infrastructure, and get the key areas of water ecological infrastructure planning. According to the principle of index system construction, the weight coefficients are determined, the comprehensive evaluation model is constructed, and the principal component analysis method is used to comprehensively evaluate the measurement of the level of aquatic ecological infrastructure construction, and to determine the spatial location, composition and composition of the BMPs aquatic ecological infrastructure in key water ecological management areas. It also guides the optimization and adjustment of urban planning and urban development and construction to realize sustainable water ecological management of the city. The results show that the planning and construction of water ecological infrastructure play a positive role in the process of urbanization, improve the urban green coverage and improve the urban ecological environment.

Keywords: Water ecological infrastructure; Urbanization process; Landscape security pattern; Principal component analysis method; Geographic information system

1. Introduction

Ecosystem is a dynamic balance system composed of all biological communities and their living environment. The natural ecosystem is composed of various systems of different sizes and shapes, ranging from a drop of water, to rivers, lakes, grasslands, forests, and oceans, to the earth that encompasses all ecosystems [1]. The various subsystems that make up these ecosystems balance each other according to their inherent laws of motion. Water ecosystem is a system composed of various organisms and environments related to water. Whether it is the natural circulation of water, or the overall or a single river and lake ecosystem, it operates according to its own laws and is always in dynamic balance. In the development of human society, mankind obtains its own greatest benefits by conquering nature, conducts large-scale resource development and neglects the exhaustion of resources, neglects the protection and recycling of resources, and causes mankind to enjoy the benefits of industrial civilization and modern technology. At the same time, it is also facing a serious crisis brought about by the incoordination between population, resources and environment. Among them, the ecological crisis is the most influential, far-reaching, and most restrictive [2]. Water is irreplaceable and extensive in the whole nature,

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and water ecosystem is the core of the whole ecosystem. The frequent occurrence of flood disasters, shortage or even depletion of water resources, water pollution of rivers and lakes, the reduction of biodiversity and the acceleration of species extinction are the main manifestations of water ecosystem destruction. Water ecology is an important part of the entire natural ecosystem, and it achieves dynamic balance according to its inherent laws [3]. However, in the process of gradual development and transformation of nature, the water ecosystem is affected by both nature and human beings, which is often negative and irreversible.

The impact of human activities on water ecological environment caused by the continuous development of urbanization process has far exceeded the impact of its natural evolution for millions of years. The process of urbanization has been greatly accelerated, the population and the scale of land occupation have increased in multiples. Any man-made changes will inevitably destroy the ecological balance of rivers, lakes and wetlands. The decline of urban water surface ratio directly leads to the reduction of storage capacity, resulting in serious water accumulation in a large area in a short period of time, which aggravates the urban heat island effect, and makes the urban aquatic animals and plants lose their habitat and destroy the biodiversity of the city. In addition, the problem of water pollution is becoming more and more serious. The main pollution sources are industrial wastewater, domestic sewage discharge, pesticide and fertilizer residues, livestock discharge and feed residue, among which domestic sewage and industrial wastewater are the most harmful. Urbanization has brought about the rapid increase and agglomeration of population, industrialization and economic development, and the increasing scale of cities. All of these have had a huge impact on the urban water ecological environment, resulting in the destruction of the natural water cycle ecosystem and the appearance of water resources. The lack of total quantity and the degradation or even deterioration of quality, the carrying capacity of the water environment exceeds the limit sufficient to destroy the structure of the water environment and the loss of ecological functions [4]. Therefore, how to avoid the damage to the ecological environment and how to restore and rebuild the water ecosystem suitable for the new situation are the problems that must be seriously studied and solved at present.

Therefore, this paper puts forward the research on the construction of water ecological infrastructure in the process of urbanization. Based on geographic information system technology, through the analysis and Simulation of regional water ecological process, the landscape security pattern of water ecological management is constructed, and the water ecological infrastructure is planned and constructed to form a complete network system of aquatic infrastructure. According to the construction principle of the index system, the weight coefficient is determined, and the comprehensive evaluation model is constructed. The principal component analysis method is used to measure and comprehensively evaluate the construction level of water ecological infrastructure, and the spatial position, composition and relationship of BMPs in key water ecological management areas are identified. And guide the optimization and adjustment of urban planning and urban development and construction, realize the sustainable water ecological management of the city, promote economic growth, and improve the level of urbanization through income effect, scale effect and structure effect.

2. Water ecological infrastructure and urbanization process

2.1. Water ecological infrastructure theory

Water ecological infrastructure represents the sustainable support capacity of natural landscape and hinterland to the city. It generally refers to the natural areas corresponding to urban built-up areas, including urban green space system, forestry and agricultural system, and nature reserve system. It can provide fresh air, food, sports, leisure and entertainment, safe shelter, aesthetic and education and other ecosystem services for the city. In order to provide the ecological network of biological habitat, in view of the change and destruction of natural system caused by traditional artificial infrastructure, the ecological design and transformation of artificial infrastructure are adopted to maintain the natural process and promote the restoration of ecological function.

Water ecological infrastructure emphasizes the core of ecosystem services. Water ecological infrastructure can provide a variety of natural, social and economic benefits for human beings, which is of great significance for the protection and cultivation of urban ecological environment and urban sustainable development [5]. Its ecosystem service value includes: providing rich and diverse habitats, local biodiversity protection, soil and water conservation, food production, climate regulation, mitigation of drought disaster, environmental purification, waste treatment, meeting the perceived needs and becoming the source of spiritual culture and education, improving the quality of living, etc.

Water ecological infrastructure emphasizes giving full play to the ecosystem comprehensive service value of water ecological infrastructure, emphasizes the coordination and mutual benefit between natural protection and human construction and development, and constructs, manages, maintains, restores and even rebuilds the ecological space network in a more active way, rather than passively retaining and isolating. Water ecological infrastructure needs systematic and multi-scale planning, forward-looking construction and maintenance, and active protection and utilization.

2.2. Classification of water ecological infrastructure

(1) According to the application scale, the water ecological infrastructure can be divided into three application levels from micro to macro, including site, land use function unit, region or watershed, as shown in Table 1.

(2) According to runoff concentration process, the typical technical measures of water ecological infrastructure can be divided into three types: source, process and terminal, as shown in Table 2.

2.3. Advantages of water ecological infrastructure

Water ecological infrastructure has the advantages of ecology, society and economy. Ecological control measures of water ecological infrastructure can reduce urban runoff coefficient, rainstorm runoff and peak value, prevent soil and water loss, regulate and store rainwater and flood, and significantly reduce the occurrence frequency of flood and desert disasters. It has good purification effect for surface runoff pollutants, which can reduce the burden of urban water. It can effectively enhance groundwater exchange and provide an effective way for water ecological infiltration, recharge water ecology and water ecological recovery and utilization [6]. In addition, water ecological infrastructure has a certain cost advantage of investment, operation and maintenance. It can also reduce the proportion of infrastructure construction, improve urban greening rate, improve urban ecological environment, and promote regional water cycle. It can provide urban public with green space and place with ecological low-carbon culture and aesthetic value for leisure, popular science education and human experience, effectively utilize urban land resources, improve the quality of regional human settlements, and promote regional development and land appreciation.

2.4. Theory of urbanization process

Urbanization is the whole process of the transformation from agricultural population to urban population, from rural residential area to urban residential area, from rural community to urban community and concentrated in the city due to the development of social productivity. Including the increase in the proportion of urban population and the number of cities, the expansion of urban land, and the increase in the proportion of urban population in the total population. Regional spread and influence, and substantial changes in the living conditions of urban residents. It is manifested in the natural increase of urban population, the large number of rural population flocking to the city, agricultural industrialization, and the rural increasingly accept the urban lifestyle [7,8]. Generally, the urbanization level is measured by the proportion of urban population in the total population. Urbanization is restricted by the level of social and economic development. From this we can see that urbanization is a complex process of population migration involving many factors such as society, economy and space. The historical process of the transformation of human production and lifestyle from rural type to urban type is mainly manifested in the transformation of rural population into urban population and the continuous improvement of cities.

The rise of urbanization began with the industrial revolution. With the popularization and basic realization of industrialization system in developed countries in Europe and the United States, industry has become the leading industry sector. A large number of bankrupt farmers have transferred from rural areas to cities. Urbanization has been rapidly promoted, the urban area has been expanding outward, the number of cities has been increasing, and the level of urbanization has been rapidly improved. The process of urbanization promotes the urbanization of population and speeds up the pace of economic construction. The process of urbanization has a periodic law (Fig. 1).

The first stage is the primary stage of urbanization. The growth of urban population is slow. When the urban population exceeds 10%, the process of urbanization gradually accelerates. When the level of urbanization exceeds 30%, it will enter the second-stage, and the process of urbanization will accelerate. This trend will not slow down until the urban population exceeds 70%. After that, it is the third stage of urbanization process, and the urbanization process is stagnant or slightly declining [9].

Table 1
Typical types of technical measures for water ecological infrastructure at three application scales

Application scale	Typical technical measures
Field	Green roof
	Permeable pavement
	Infiltration ditch
	Collection and recycling system
	Bioretention infiltration system
Land use functional unit	Low potential green space
	Ecological landscape water body
Area or watershed	Green corridor
	Infiltration pond

3. Water ecological infrastructure planning

Water ecological infrastructure planning is a special plan of urban planning. Its core is to systematically protect and plan water ecological infrastructure from different perspectives such as water cycle, water safety, water environment, and water resources under the guidance of the concept of water ecological management. Type, scale, layout, structure, etc., form a complete network system of water ecological infrastructure, and realize sustainable water ecological management of the city.

3.1. Water ecological infrastructure planning system

The systematic ecological spatial network of water ecological infrastructure includes three components:

Table 2
Typical types of technical measures for aquatic ecological infrastructure in the three runoff convergence processes

Runoff concentration process	Typical technical measures
Source	Facilities for controlling and utilizing water ecology from the source
Process and transmission	With transmission function, pre-processing small-scale facilities
Terminal	Facilities capable of large-scale or terminal treatment of water ecology

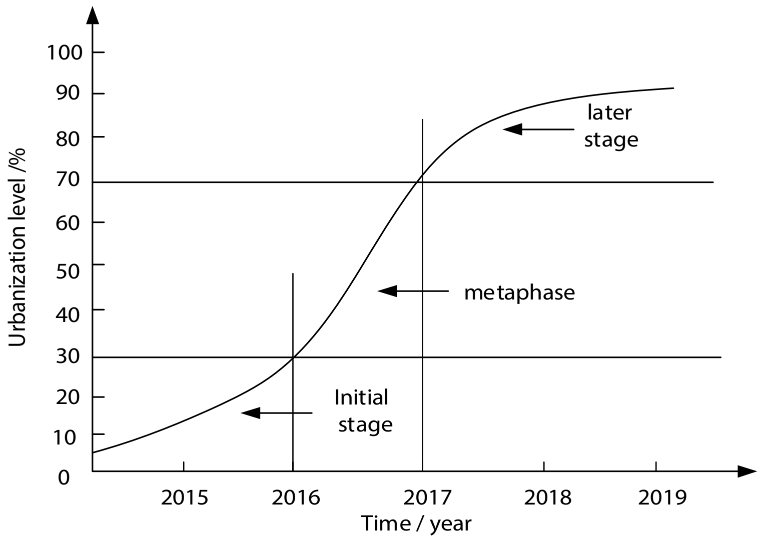

Fig. 1. The regularity of the urbanization process.

BMPs water ecological infrastructure, LID water ecological infrastructure and transmission-type water ecological infrastructure [10]. The water ecological infrastructure network system is shown in Fig. 2.

BMPs water ecological infrastructure is the core water ecological infrastructure with centralized and terminal control, which has the greatest impact on regional water ecological management and plays an irreplaceable key role in urban water ecological management. Its construction, management and maintenance are generally dominated by the government. LID water ecological infrastructure is a decentralized, source and process controlled small-scale water ecological infrastructure of each land development unit or plot. Its construction, management and maintenance are generally entrusted by the government or required by the construction party and users. Transmission type water ecological infrastructure generally refers to green roads, green watercourses and ecological pipe network facilities. BMPs water ecological infrastructure and lid water ecological infrastructure are connected into an organic network to form a complete water ecological infrastructure system [11]. Among them, the water ecological management of key areas is jointly undertaken by BMPs water ecological infrastructure and LID water ecological infrastructure, while non-key areas are undertaken by LID water ecological infrastructure.

Aiming at the three compilation stages of urban planning and the corresponding three research scales from macro to micro, the system of water ecological infrastructure planning is divided into three levels (Fig. 3).

The macro scale overall planning of water ecological infrastructure connects with the compilation stage of urban master plan, focusing on the planning of BMPs water ecological infrastructure network with regional core, centralized and terminal control. The meso scale regulatory planning of water ecological infrastructure, docking the regulatory planning stage, focuses on the source and process control, decentralized LID water

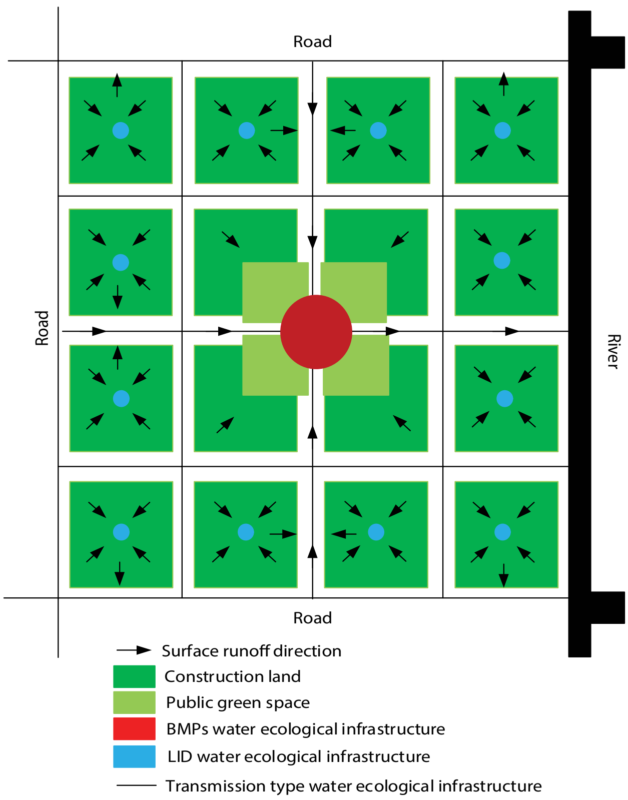

Fig. 2. Water ecological infrastructure network system.

ecological infrastructure planning. As well as the micro-scale construction planning of the site's water ecological infrastructure, it is connected to the construction planning stage. The construction planning has entered the planning implementation and project management level. Its main content is the BMPs water ecological infrastructure and LID water ecological foundation of the site.

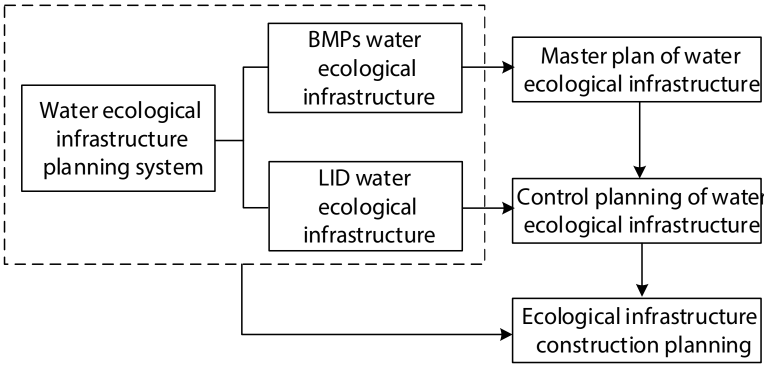

Fig. 3. Water ecological infrastructure planning system.

The facility proposes specific arrangements and detailed planning and design to guide the construction of water ecological infrastructure projects.

3.2. Water ecological infrastructure planning method

The theory of landscape security pattern emphasizes the mutual relationship and coupling mechanism between pattern and process, and holds that there is a potential strategic pattern composed of key landscape elements, location and spatial relationships, namely landscape security pattern. Landscape security pattern plays an important role in the integrity, health and safety of the landscape process. Through the spatial simulation and analysis of the ecological process, we can distinguish the landscape security pattern, realize the effective control of the ecological process, maintain the integrity of the ecological process with the least land and the minimum ecological structure, and ensure the play of the overall ecosystem services [12]. At the regional scale and urban planning level, the main consideration is the protection and planning of water ecological infrastructure of large terminal control and centralized core BMPs. The spatial analysis and simulation of regional hydrological and ecological processes can identify the spatial location, components and relationships of the core BMPs aquatic ecological infrastructure of strategic significance for regional water ecological management. Constructing a regional water ecological management landscape security pattern, maintaining and strengthening the integrity of the urban natural hydrological process, and then realizing effective management of urban water ecology. The water ecological management landscape security pattern is the planning result of water ecological infrastructure planning.

Geographical information system is a computer-based comprehensive application technology. The powerful spatial analysis methods and technologies of geographic information system provide an effective way for the simulation and analysis of hydrological and ecological processes. Hydrological models are used to simulate and analyze regional runoff generation. The hydrological model is based on the water balance formula and two basic assumptions. The water balance formula can be expressed as:

$$Q = W_s + E + R \tag{1}$$

where Q represents the total rainfall of a certain rainfall event, W_s represents the initial loss value, which mainly refers to plant interception, initial infiltration, and filling water storage on the underlying surface, E represents the actual infiltration volume, and R represents the surface runoff.

Assume that the ratio of the actual infiltration amount E to the actual runoff R of a rainfall event in the catchment area is equal to the ratio of the maximum possible detention amount A to the potential runoff S in the catchment area, namely:

$$\frac{E}{R} = \frac{A}{S} \tag{2}$$

Assume that the potential runoff S is the difference between the total rainfall Q and the initial loss W_s, namely:

$$S = Q - W_s \tag{3}$$

Then, the empirical relationship between W_s and A is expressed as:

$$W_s = \lambda A \tag{4}$$

where λ represents a constant, usually 0.2.

It can be concluded that the basic runoff generation formula of the hydrological model is:

$$R = \frac{\left(Q - W_s\right)^2}{Q - W_s + A}, Q \geq W_s \quad R = 0, Q < W_s \tag{5}$$

where A is the only uncertain parameter with a large variation range. For this reason, a dimensionless parameter, the number of runoff curves D, is introduced, and the relationship between A and D is established as follows:

$$A = 254\left(\frac{100}{D}\right) - 1 \tag{6}$$

where D is a dimensionless parameter that can reflect the comprehensive characteristics of the underlying surface factors of the catchment area, land use, land cover, soil type, and previous soil moisture conditions.

According to the soil runoff generation capacity under the same precipitation and surface conditions, the soil is divided into four hydrological groups, as shown in Table 3. The soil runoff generation capacity is mainly affected by the minimum soil permeability.

According to the API index of the previous precipitation, the AMC level of the previous soil humidification conditions is divided, and the calculation formula is:

$$\text{API} = \sum_{i=1}^{n} P_i \tag{7}$$

where P_i represents the precipitation of the previous i days, which is generally 5 d. According to the API index of the previous precipitation, the AMC of the previous soil humidification conditions is divided into three types: I (dry), II (medium), and III (wet), as shown in Table 4.

The PLOAD model is used to calculate the non-point source pollution load of the basin, and the relationship between land use type and non-point source pollution load is established. The combination of PLOAD model and hydrological model can be widely used for non-point source pollution load prediction of urban land, agricultural land and undeveloped land [13]. It is suitable for the simulation of the total pollution load of regional surface runoff at the macro-scale stage of the city's overall planning. The calculation formula of the PLOAD model is:

$$L = \sum_{j=1}^{n} K_j H_j G_j \tag{8}$$

where L represents runoff pollution load, K_j represents the catchment area of the j land use type, and H_j represents the runoff depth of the j land use type. According to the calculation results of the hydrological model, G_j represents the average concentration of pollutants in the rainfall event of the j land use type. In the process of a rainfall event, the pollutant concentration of runoff pollution changes greatly and has the initial scouring effect. Therefore, the average concentration of pollutants in the runoff of a rainfall event is often used to represent the average concentration of a certain runoff pollutant in the whole process of a rainfall event, that is, the flow weighted average value of pollution concentration of sampling samples in the whole process of a rainfall event.

3.3. Water ecological infrastructure planning process

The planning and research process of water ecological infrastructure based on the theory of water ecological infrastructure and water ecological management landscape security pattern (Fig. 4).

Based on the geographic information system technology environment, analyze and simulate the regional aquatic ecological process, and draw the key areas of the aquatic ecological infrastructure planning. Combined with the comprehensive evaluation of BMPs aquatic ecological infrastructure construction level measurement, the spatial location, composition and relationship of BMPs aquatic ecological infrastructure in key water ecological management areas are identified, and the contribution of the minimum ecological structure to the overall ecosystem services is emphasized. Water ecological management landscape security pattern, and guide the optimization

Table 3
Standards for classification of soil hydrological groups in hydrological models

Soil hydrology group	Soil texture	Minimum permeability (mm/h)
A	Thick layer sand, thick loss, agglomerated silt soil	7.25–11.43
B	Thin loess, sandy loam	3.80–7.25
C	Clay loam, thin sandy loam, soil with low organic matter content or high clay content	1.25–3.80
D	Soil that swells significantly after absorbing water, plastic soil, some saline soil	0–1.25

Table 4
AMC classification standard for soil humidification conditions in the early stage

AMC grade	Total rainfall in the first 5 d	
	Plant dormancy period	Plant growth period
AMC I: The soil is dry, but it does not reach the plant wilting point, so it has good cultivation and cultivation	<12	<35
AMC II: The average condition at the time of flooding, that is, the average condition of soil moisture in the basin on the eve of flooding	12–28	35–52
AMC III: Heavy rain or light rain and low temperature occurred in 5 d before the heavy rain, the soil moisture is almost saturated	>28	>52

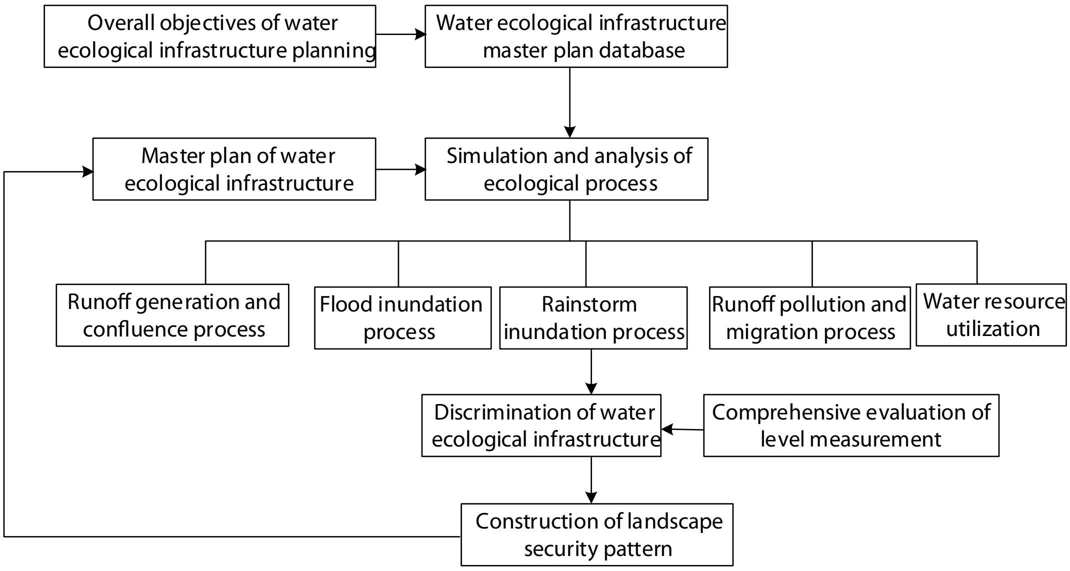

Fig. 4. Water ecological infrastructure planning process.

and adjustment of urban planning and urban development and construction.

4. Measurement analysis of water ecological infrastructure construction level

4.1. Construction principles of index system

By formulating and following the corresponding principles, determine the relationship between various factors, use the index system construction method for comprehensive analysis [14], follow the following principles to design the evaluation index system of water ecological infrastructure.

(1) The principle of integrity: it is a concept that can fully reflect the level of aquatic ecological infrastructure construction, so it should fully reflect the content that needs to be evaluated.
(2) The principle of simplicity: on the basis of comprehensive reflection of water ecological infrastructure, the contents reflected should not be repeated as far as possible to ensure that the indicators are not affected by overlapping factors.
(3) The principle of comparability: on the one hand, it should be able to be linked with the standards of national authorities, on the other hand, it should also be convenient for horizontal comparison with other systems.
(4) The principle of hierarchy: due to the complexity of indicators, the first level of indicators is often large and cannot reflect the essence of the problem. The index system is divided into multi-level levels to comprehensively and clearly reflect the problems.
(5) The principle of operability: the indicator system should have its reality and operability, and it must be able to express quantitatively or accurately measure related content, and pay special attention to operability in the construction of the indicator system.

4.2. Determine the weight coefficient

The weight is the score indicating the role of each index in various evaluation, and the determination of the weight has an important impact on the local and overall evaluation of the city [15]. In the same group of index values, different weight coefficients may lead to different evaluation results. In the evaluation of multi index problems, according to the difference of weight selection methods, it can be divided into:

(1) Subjective weighting method: according to subjective experience or expert evaluation, the weight of each index in the comprehensive evaluation index system can be set. It is a qualitative evaluation method, including multi-level fuzzy evaluation and multi-level grey evaluation.
(2) Objective weighting method: according to the internal relationship of each index in the evaluation index system, the quantitative evaluation method of each index weight is determined by multivariate statistical analysis method, which mainly includes principal component analysis, analytic hierarchy process, etc.

This paper mainly uses principal component analysis and SPSS17.0 statistical software for analysis and statistics. Principal component analysis (PCA) is a statistical data analysis method, which can change multiple variables into another group of unrelated variables through linear transformation. After the transformation, the variables are arranged in the order of decreasing variance, and the total variance of the variables can be ensured unchanged before and after the transformation. Since the variance of the first variable is the largest, it becomes the first principal component; and the second variable is called the second principal component, and the second variable is not related to the first variable [16].

Assuming that two index variables are needed for the measurement of an entity, the second variable can be reflected according to the change related quantity of the first variable. If the difference of the second variable is too large, only the first variable will be considered, thus reducing the number of variables considered. Assuming that on the vertical and horizontal axes, Y_1 and Y_2 can be expressed as a linear combination of X_1 and X_2, then Y_1 and Y_2 are the first and second principal components of the index variables X_1 and X_2, respectively.

4.3. Build a comprehensive evaluation model

Before analyzing the data, it is usually necessary to standardize the data. In this paper, dimensionless data processing is adopted to solve the problem of data comparability. In order to eliminate the influence of dimension and order of magnitude in multi index comprehensive evaluation by principal component analysis, the mean method is used as dimensionless processing method [17]. The covariance matrix of new data column after dimensionless averaging method contains all information of original data.

Standardize the data based on the mean and standard deviation of the original data, and standardize the original value β using z-score to get β′, namely:

$$\beta' = \frac{(\beta - \alpha)}{\delta} \tag{9}$$

where α represents the mean and δ represents the standard deviation.

By analyzing the essence of the principal component method, the principal component calculation steps are designed as follows, and the observation sample data matrix is set as:

$$U = \begin{bmatrix} u_1 & \cdots & u_{1m} \\ \cdots & \cdots & \cdots \\ u_{1n} & \cdots & u_{\mathrm{nm}} \end{bmatrix} \tag{10}$$

where n represents the number of samples and m represents the number of variables. According to the matrix P, find the eigenvalue χ and its corresponding eigenvector $K = \{K_1, K_2, \ldots, K_m\}$, from which the eigenvectors form a new eigenvector, namely:

$$Z = U\left(\chi K_1 + \chi K_2 + \cdots + \chi K_m\right) \tag{11}$$

Select σ principal components to calculate the comprehensive evaluation value, set the contribution rate of ω as the principal component, and the cumulative contribution rate of θ as the principal component. When θ is close to 1, the first τ index variables are selected, and the principal components become τ index variables, and the index variables are reduced to o. Then the comprehensive evaluation model for water ecological infrastructure construction is:

$$Z_j = \frac{\sigma}{\theta}\left[\omega\left(oK_1 + oK_2 + \cdots + oK_m\right)\right] \tag{12}$$

Through the above steps, the construction level of water ecological infrastructure is measured by the principal component analysis method. It can be seen that the construction level of water ecological infrastructure generally has a steady upward trend, which promotes the economic growth. Through the income effect, scale effect and structure effect, the urbanization level is improved, and then the urban economic growth is promoted. At the same time, water ecological infrastructure construction, improve the economic investment environment, so as to promote the upgrading of technology and the formation of material capital.

5. Empirical analysis

5.1. Water ecological infrastructure construction examples and model setting

In this paper, a representative region of a city is selected as the research case, and the region is divided into three regional levels: the central district, the suburban area and the outer suburb district. Comparing the population change of the region from 2015 to 2019, the population growth curve of the region as shown in Fig. 5.

According to Fig. 5, the total population of the central area is decreasing, showing the rule of agglomeration first and then gradually spreading, and the proportion of the urban population increases first and then decreases continuously. In the initial stage of urbanization, the population in the outer suburbs is concentrated to the central city. With the urbanization to a higher stage, the population further spread to the outer circle of the metropolitan area, that is, the outer suburbs. Its proportion in the total population of urban areas will first increase, then stabilize, and then decrease. The total population in the suburbs is increasing. In the long period of urbanization, the population is derived from the central city and the suburbs. The proportion of the urban population remains a downward trend. It is only when the suburbs of urbanization spread more. At the high stage, the central point of antimagnetic force begins to form, and there is a continuous and ever-increasing population migration. Compared with the construction of water ecological infrastructure in the region from 2015 to 2019, the construction of water ecological infrastructure in the region is shown in Table 5.

According to the data in Table 5, from 2015 to 2019, the total area of green coverage in this area increased from 32.51 to 514.41 million m^2, the area of garden green space increased from 5.981 to 14.328 million m^2, and the area of water source green space increased from 650.3 to 12.73 million m^2. It can be seen that the greening construction in this area has been strengthened, and the greening coverage rate has increased year by year.

Through the theoretical analysis of this paper, it is believed that the construction of water ecological infrastructure will promote economic growth and industrial structure upgrading, which will bring residents' income effect, and then attract population to move to cities and towns, and promote urbanization. Therefore, this article combines the model setting method to add per capita FDI inflow to the model setting, and sets the model as:

$$\text{LnURBANt} = \text{LnINFRAt} + \text{LnFDIt} + \mu_t \quad (13)$$

where URBAN represents the proportion of the population in the total population to measure the level of urbanization. The higher the proportion, the higher the level of urbanization. INFRA represents the overall level of water ecological infrastructure development score data, and FDI represents per capita regional production. The total value, μ_t represents the random disturbance term.

5.2. Impact of water ecological infrastructure construction on urbanization

In this paper, the unit root test method of ADF is used to perform unit root test on the time series LnINFRA, LnFDI, and LnURBAN. The test results are shown in Table 6.

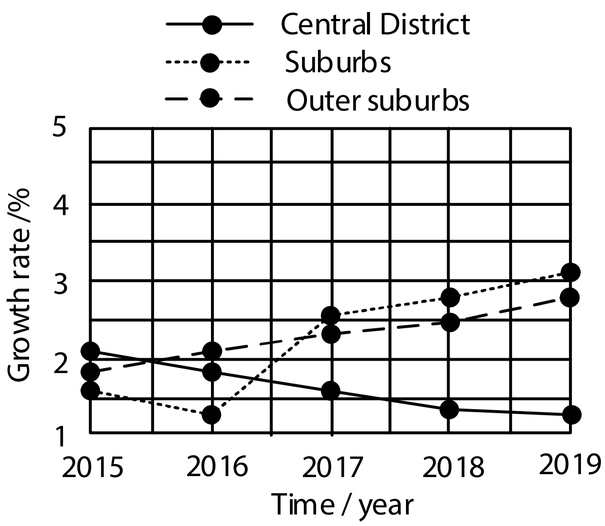

Fig. 5. Regional population growth rate curve.

According to the data in Table 6, LnINFRA, LnFDI, and LnURBAN are all stable, so the co-integration test can be done directly to check whether there is a long-term equilibrium relationship between the variables. The results of the co-integration test are shown in Table 7.

According to the data in Table 7, there are at least four co-integration relationships among variables. The effect of water ecological infrastructure construction level on urbanization is positive. For every 1% increase in water ecological infrastructure construction level, the urbanization rate will increase by 0.014%. However, the significance is weak, which indicates that the direct effect of water ecological infrastructure construction on urbanization is not obvious, because the construction level of water ecological infrastructure is quite different, which leads to the low level of water ecological infrastructure construction.

5.3. Impact of different types of water ecological infrastructure construction on urbanization

According to the model set by Eq. (13), the water ecological infrastructure construction level is set as green corridor infrastructure, ecological landscape water infrastructure, green roof infrastructure and other different types of water ecological infrastructure. The unit root test results of the above variables are shown in Table 8.

According to the data in Table 8, LnINFRA, LnFDI, and LnURBAN are all stable, so the co-integration test can be done directly to check whether there is a long-term equilibrium relationship between the variables. The results of the co-integration test are shown in Table 9.

According to the data in Table 9, when the level of green corridor infrastructure increases by 1%, the level of urbanization will increase by 0.33%, and the effect is significant. This is because the more developed green corridor infrastructure, the higher the efficiency of urban ecological development, the city will expand greening, the demand for green ecology will increase, thus

Table 5
Regional water ecological infrastructure construction

Years	Total area covered by greening/10,000 m^2	Garden green area/10,000 m^2	Water source green area/10,000 m^2	Green coverage rate (%)
2015	3,251	598.1	650.3	38.4
2016	3,612	765.3	701.2	40.6
2017	4,602	982.4	1,143.7	46.2
2018	4,832	1,265.9	1,068	48.3
2019	5,144	1,432.8	1,273	52.6

Table 6
ADF unit root test results

Variable	(C, T, K) DW value	ADF value	1% threshold	5% threshold	10% threshold	Conclusion
LnINFRA	(C, T, 0) 2.01	–5.51	–4.42	–3.62	–3.25	I (0)
LnFDI	(C, 0, 0) 1.86	–4.63	–3.63	–2.95	–2.61	I (0)
LnURBAN	(C, T, 0) 1.80	–5.02	–4.25	–3.54	–3.21	I (0)

Table 7
Co-integration test results of water ecological infrastructure construction level

Concordant	Characteristic value	Trace statistics	Critical value (0.05)	Probability *p*
None	0.9298	134.2699	75.9828	0.0000
At most 1	0.7987	78.5154	55.0260	0.0001
At most 2	0.5987	48.6654	34.1928	0.0015
At most 3	0.4836	20.8983	19.2626	0.0285

Table 8
Unit root test results of different types of water ecological infrastructure construction

Variable	(C, T, K) DW value	ADF value	1% threshold	5% threshold	10% threshold	Conclusion
LnINFRA	(C, T, 0) 1.90	–4.42	–3.62	–3.24	–2.32	I (0)
LnFDI	(C, 0, 0) 2.06	–4.44	–3.63	–3.25	–2.70	I (0)
LnURBAN	(C, T, 0) 1.84	–2.99	–3.03	–2.65	–1.65	I (0)

Table 9
Co-integration test results of different types of water ecological infrastructure construction levels

Different types	Concordant	Characteristic value	Trace statistics	Critical value (0.05)	Probability *p*
Green corridor infrastructure	None	0.9298	134.2699	75.9828	0.0000
	At most 1	0.7987	78.5154	55.0260	0.0001
	At most 2	0.5987	48.6654	34.1928	0.0015
	At most 3	0.4836	20.8983	19.2626	0.0285
Ecological landscape water infrastructure	None	0.9130	104.7204	60.0614	0.0000
	At most 1	0.6941	50.9899	40.1749	0.0029
	At most 2	0.4049	24.9344	24.2760	0.0413
	At most 3	0.3475	13.5150	12.3209	0.0314
Green roof infrastructure	None	0.9119	148.4579	60.0614	0.0000
	At most 1	0.8906	144.5045	40.1749	0.0016
	At most 2	0.6968	95.0106	24.2760	0.0040
	At most 3	0.6486	84.0356	12.3209	0.0271

promoting the construction of water ecological infrastructure. Ecological landscape water infrastructure construction has a significant positive effect on urbanization, which shows that with the development of ecological landscape and the improvement of life quality, people pay more attention to the living environment, low-carbon economy and ecological civilization. When the level of green roof infrastructure construction increases by 1%, the level of urbanization will increase by 0.431%. This shows that the development of green ecology has become an important factor of urban attraction and plays an important role in promoting urbanization. In conclusion, FDI plays a positive role in the process of urbanization in the level of water ecological infrastructure construction, and different types of water ecological infrastructure construction have improved the role of urbanization.

6. Conclusion

In this paper, the construction of water ecological infrastructure in the process of urbanization is studied. Under the GIS technology environment, the regional water ecological process is simulated and analyzed, and the water ecological infrastructure is planned and constructed to form a complete network system of water ecological infrastructure. Comprehensive evaluation of water ecological infrastructure construction level measurement, identify the spatial location, components and relationship of BMPs water ecological infrastructure in key water ecological management areas, and guide the optimization and adjustment of urban planning and urban development and construction, so as to realize the sustainable water ecological management of the city. The construction of water ecological infrastructure has played a positive role in promoting the process of urbanization, attracting the population to move to the city, improving the urban green coverage and improving the urban ecological environment.

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