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Research on the design and optimization of ecological landscape water body network based on linear programming

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ABSTRACT

With the rapid development of the regional economy, the urbanization process is gradually accelerated, and the ecological safety problems of the urban water body network gradually appear, so this paper is based on linear planning to optimize the ecological landscape water body network. The study first gives a detailed description of the linear planning theory and highlights the gray linear planning model used. Based on the ecological constraints of the landscape pattern quantity optimization research, the “top-down” gray linear planning model from six aspects to build ecological constraints and objective function, through the simplex method to solve, resulting in different scenarios of the total amount of control of the optimization program. Three practicable optimization scenarios are obtained through repeated debugging of the optimization results, and the three scenarios achieve different results in terms of economic and ecological values. In this paper, effective optimization schemes are proposed for different optimization purposes, which on the one hand make the optimization results more realistically reflect the changes of the ecological landscape water body network, and on the other hand provide an optimal model for the management and development of the ecological landscape water body network, and promote the sustainable development of the region.

Keywords: linear programming, gray linear programming model, ecological constraints, landscape water body network, optimization scheme

1. Introduction

Water is the source of human life and the earliest place of human activities. In modern urban construction, out of people's demand for improved quality of life and the need for ecological environmental protection, ecological landscape water body network design has become a trend. At present, the ecological landscape water body in the city has certain design value. On the one hand, in urban landscape design, the application of water body landscape is more and more extensive, which

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can not only increase the urban greening area, but also improve and regulate the urban microclimate, and increase the degree of the city's interesting and cultural taste [1-4]. On the other hand, the water body landscape design as a kind of visual art, so that people have a sense of immersion, to a certain extent, can make up for the urban green space, garden green space in the architectural vignettes and other landscape forms of deficiency, rich urban landscape content [5-8]. From the design idea, the design form of water landscape can be divided into natural design and imitation natural design [9-10]. The natural design of water landscape is mostly based on rivers, lakes, ponds and other natural water bodies as the background of the landscape, and the coordination of the surrounding environment [11-12]. While the imitation nature-style design is generally formed by artificial construction or simulation of natural ecosystems, is a more ideal form of water landscape, such as artificial lakes, fountains and waterfalls [13-14]. As the ecological landscape water body in the city is closely related to the urban development planning, the design should fully consider the coordination with the urban development planning, to ensure that the artificial water body landscape design is integrated with the overall planning of the city, and to enhance the overall effect of the artificial water body landscape [15-18].

In this paper, linear programming is used to optimize the design of urban ecological landscape water body network. Based on the ecological constraints, gray linear programming is used to construct ecological constraints and objective functions from six aspects and solve them. After the optimization of the ecological landscape water network, taking into account the real needs and feasibility, three optimization methods are simulated, and the changes in the ecological landscape water network of different schemes are analyzed, as well as the economic and ecological value of the comparative analysis, so that the ecological landscape water network design has an effective planning method.

2. Design methods based on linear programming algorithms

2.1. Linear Programming

The optimization theory of ecological landscape pattern considers that the landscape pattern determines the generation and change of ecological processes, and the ecological processes can in turn adjust and maintain the existing landscape pattern. There are many methods to optimize the ecological landscape water body network design in terms of quantitative structure, mostly using different mathematical models, and the more representative ones are linear programming, gray linear programming, multi-objective linear programming and system dynamics model.

In this paper, the research is carried out on the basis of linear programming, first of all, the linear programming method is generalized, and its three elements include variables, linear objective function and linear constraints, as well as standard type expressions, general type expressions, matrix and vector expressions and so on.

The linear programming method consists of three components including variables, linear objective function and linear constraints. The linear objective function and linear constraints are linear expressions for the variables, the linear objective function can be expressed as a maximum or minimum value, and the linear constraints can be expressed as a set of equations or a set of inequalities. A set of assignments of the variables that satisfy the linear constraints is the solution of linear programming, and the value of the linear objective function obtained through this set of assignments is the objective of linear programming. The basic steps for establishing a mathematical model using the linear programming method are:

1) Determine the variables affecting the objective of linear programming.
2) List the linear objective function equation.
3) Write the linear constraints.

The standard type of linear programming problem is:

$$\begin{aligned} &\max(\min)\, z = c_1x_1 + c_2x_2 \cdots + c_nx_n \\ s.t.\quad &a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \le (=,\ge) b_1 \\ &a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \le (=,\ge) b_2 \\ &\cdots\cdots \\ &a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \le (=,\ge) b_m \\ &x_j \ge 0\,(j = 1, 2, \ldots n) \end{aligned} \tag{1}$$

The above linear programming problem can be abbreviated as:

$$\max(\min)\, Z = \sum_{j=1}^{n} c_j x_j \tag{2}$$

$$s.t.\quad \sum_{j=1}^{n} a_{ij}x_j \le (=,\ge) b_i \quad x_j \ge 0 \tag{3}$$

The above linear programming problem can also be notated in the form of matrices and vectors:

$$\max(\min) Z = CX \tag{4}$$

$$s.t.\quad AX \le (=,\ge) b \quad X \ge 0 \tag{5}$$

Among them:

$$C = (c_1 \quad c_2 \quad \ldots \quad x_n) \tag{6}$$

$$X = \begin{pmatrix} x_1 \\ x_2 \\ \cdots \\ x_n \end{pmatrix} \tag{7}$$

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & & & \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix} \tag{8}$$

$$b = \begin{pmatrix} b_1 \\ b_2 \\ \cdots \\ b_n \end{pmatrix} \tag{9}$$

2.2. Gray Linear Programming Model

In the practical application of many linear programming models, the gray linear programming model, with good ability to solve nonlinear problems, and the use of a high degree of adaptability, has been widely used in many industries.

In system theory, the color shades are often used to distinguish the degree of clarity of the information, the black color system means that the information inside the system is completely unknown, the white system means that the information inside the system is completely known, between the black system and the white system is called the gray system. Traditional systems theory studies mostly systems with sufficient and clear internal information. For some systems with poor and relatively ambiguous internal information, people have utilized the black-box method to conduct research, and have also achieved more successful experience. However, some systems with partially conclusive and partially ambiguous internal information have been poorly studied and no substantial progress has been made.

In general linear programming models, at least one coefficient (price coefficient, constraint quantity, or element in A) is gray or determined by the theory and methods of gray systems, then this type of problem is a gray linear programming problem. Compared with other linear programming models, the gray linear programming model is more mature and widely used, and makes up for the shortcomings of the general linear programming model.

Gray linear programming is different from white linear programming (i.e., linear programming where internal information is completely known). The differences are:

1) In a gray linear programming model, the constraint values of the constraints are indeterminate and can change over time rather than a specific value.

2) The model system can drift (change) within a certain range with upper, lower and interval whitening values.

3) The objective function of the system model is not necessarily a mathematical extreme value (very large max or very small min), but rather a relatively optimized value or a gray interval value (gray target).

Gray linear programming model can provide more information available in the planning program decision-making options, after the model running calculations can be obtained from a number of groups of optimization solutions, each group of optimization solutions to form a feasible program can be selected from a number of feasible programs in the phase complementary, integrated and other functions, to obtain a variety of alternative optimization programs, and then integrated the specific circumstances of the optimal selection of feasible programs.

The mathematical model of gray linear programming is

$$f(x) = \otimes(c)X^T \to \max(\text{or} \min) \tag{10}$$

where $\otimes$ is the gray parameter and $\otimes(c) = \left[\otimes(c_1), \otimes(c_2), \cdots, \otimes(c_n)\right]; s.t. \otimes(A)X \le \otimes(B); x \ge 0$.
where:

$$\otimes(A) = \begin{bmatrix} \otimes(a_{11}) & \otimes(a_{12}) & \cdots & \otimes(a_{1n}) \\ \otimes(a_{21}) & \otimes(a_{21}) & \cdots & \otimes(a_{2n}) \\ \cdots & \cdots & \cdots & \cdots \\ \otimes(a_{m1}) & \otimes(a_{m2}) & \cdots & \otimes(a_{mn}) \end{bmatrix} \tag{11}$$

$$\otimes(B) = \left[\otimes(b_1), \otimes(b_2), \cdots \otimes(bm)\right] \tag{12}$$

Gray linear programming is one of the optimal planning methods found in the current research, which can dynamically reflect the social, economic and environmental development changes and resource allocation, and has been widely used in the study of variable systems.

By studying and learning from the existing research results, the algorithm design flow of gray linear programming solution in this thesis is shown in Figure 1.

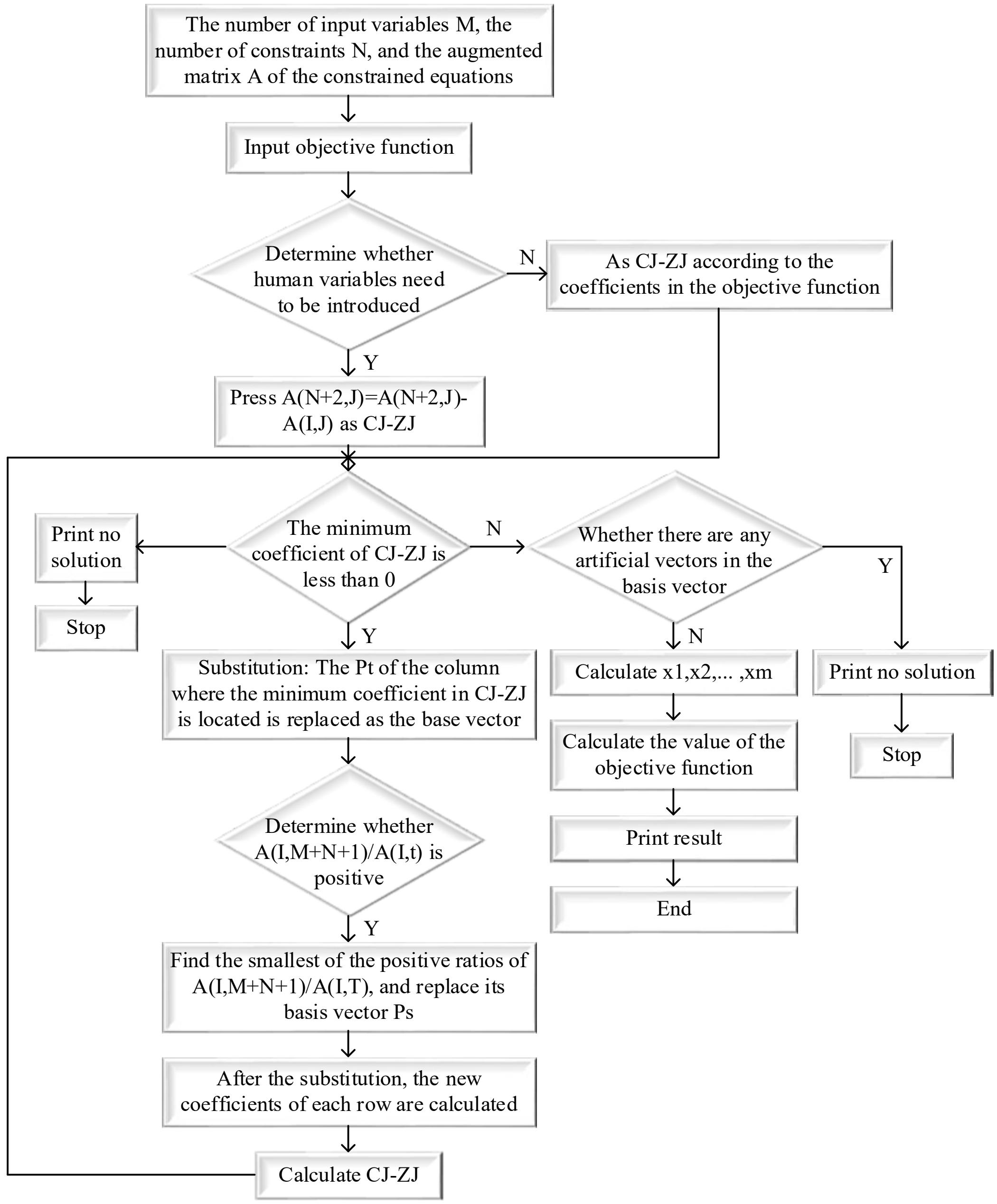


Fig. 1. block diagram of grey linear programming algorithm design

2.3. *Optimization of landscape water body network design based on ecological constraints*

This paper is oriented to the optimization of ecological landscape water body network design including the optimization of quantity and spatial structure, the quantity of grey linear programming model ecological landscape water body network design optimization process is shown in Figure 2. There are roughly two tendencies in the scheme of grid optimization, i.e., the economic priority scheme aiming at pursuing economic benefits, and the ecological optimization scheme aiming at ecological protection. Here, this paper takes the maximum ecological benefit as the goal of landscape pattern optimization, sets the critical conditions for the control of the total number of landscape types, adopts grey linear programming for the calculation of the total number of types, and further selects the optimal scheme through the comparative analysis of different control schemes. This chapter mainly includes the setting of decision variables, the setting of constraints, the establishment of objective function, model solving and the selection of scheme.

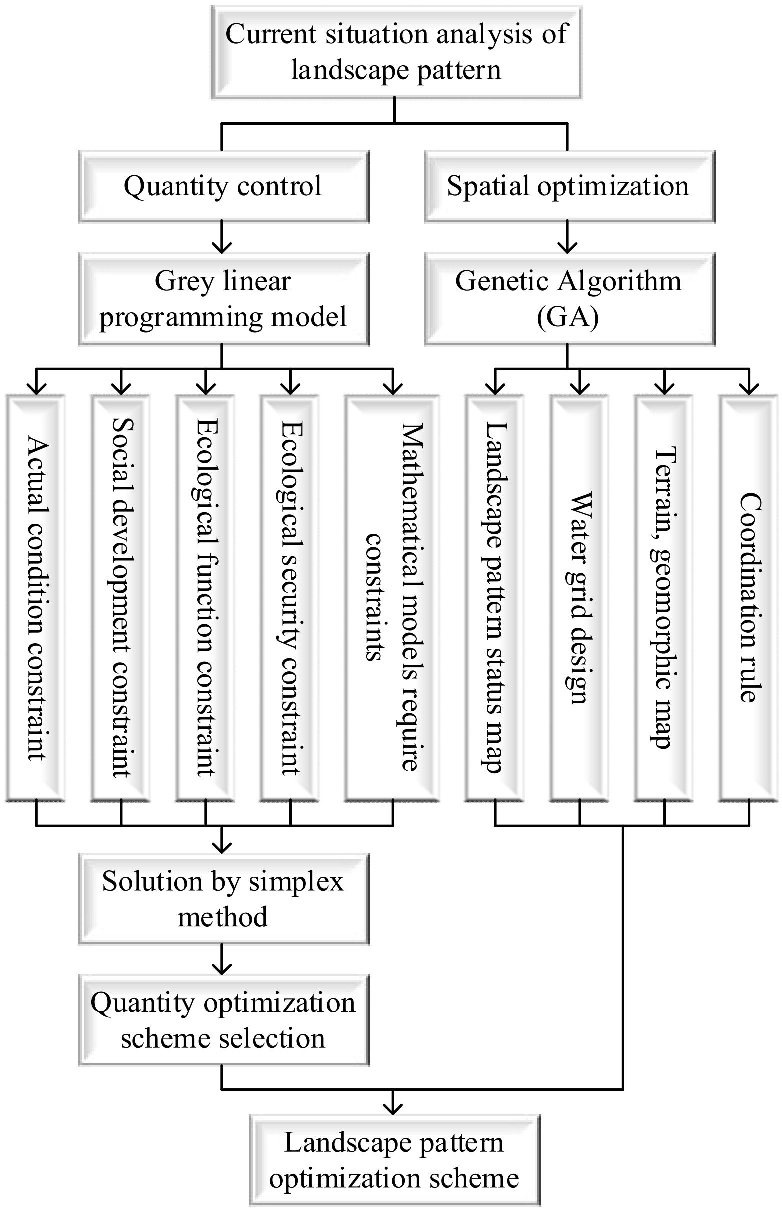


Fig. 2. Ecological landscape water grid design optimization process

Linear programming is an effective method of optimizing resource allocation, a mathematical method of selecting the optimal configuration scheme from all possible alternatives through the established objectives under certain constraints and limitations, and is commonly used in the study of multivariate complex systems. However, the general linear programming model has the following defects:

First, as a definite static model, it requires that the benefit coefficients in the objective function, the technical coefficients in the constraints and other limiting quantities are fixed, which makes the model unable to reflect the constraints over time.

Second, it is inconvenient to deal with gray numbers in the model or constraints, which affects the results.

Thirdly, due to the dynamic variability of the landscape pattern and the complexity among ecosystem elements, the computational problems often make the solution sought inconsistent with the reality, or even no solution.

There are three preconditions for modeling and use of gray linear programming methods:

1) Optimization conditions. The objective function is a linear relationship, and can be expressed in

terms of the extreme value (maximum or minimum), and its extreme value represents the optimal value of the function of the system under study.
2) Constraints. Structural optimization is a relative result under the influence and constraints of multiple limiting factors. Such constraints can be expressed in terms of linear algebraic formulas (equations or inequalities) for each variable.
3) Program Optimization. According to different objectives and requirements, a number of preferred programs can be derived, and an optimal program can be selected through feasibility study. Satisfying the above conditions, the linear programming model can be used to solve.

The general form of gray linear programming is:

$$\max(\min)Z = CX = \sum_{i=1}^{n} c_i x_i \tag{13}$$

Satisfaction:

$$\begin{cases} \otimes(A)X \le (=,\ge)b \\ X \ge 0 \end{cases} \tag{14}$$

where Eq. (13) is the objective function of gray linear programming and Eq. (14) is the constraints of gray linear programming.

Let $x=[x_1,x_2,...,x_n]^T$ be a vector of decision variables and $x_i \ge 0; C=[c_1,c_2,...,c_n]$ be a vector of value coefficients of the objective function, where $c_j(j=1,2,...,n)$ can be a gray number, which can be predicted by GM(1, 1). The objective function can reflect the interdependence and constraints between the functional goals of the system and its structure and characteristics The great or small value of the objective function represents the optimal value of the system function.

Its constraints are $\otimes(A)X \le (=,\ge)b,\ X \ge 0$ and the coefficient matrix of the constraints is:

$$\otimes(A) = \begin{bmatrix} \otimes(a_{11}) & \dots & \otimes(a_{1n}) \\ \dots & & \dots \\ \otimes(a_{m1}) & \dots & \otimes(a_{mn}) \end{bmatrix} \tag{15}$$

In Eqs. $\otimes(a_{ij}) \in \left[\underline{a_{ij}}, \overline{a_{ij}}\right]$, $\underline{a_{ij}}$ and $\overline{a_{ij}}$ are the lower and upper values of $\otimes(a_{ij})$. For each constraint the corresponding constraint quantity $b=[b_1,b_2,...,b_m]$ can also be predicted by GM(1, 1).

In performing the gray linear programming solution process, the gray parameters are first whitened, usually by specifying the values of the elements in A, i.e., whitening the elements in $\otimes(A)$. You can take the minimum whitening value, or the maximum whitening value, or other whitening values in the interval $\left[\underline{a_{ij}}, \overline{a_{ij}}\right]$ for calculation, the constraint coefficients take a different value, the results obtained by the difference, so it should be based on the actual situation to take the value.

The constraint value b can be obtained in this way, if for the ind constraint value $b_i(i=1,2,...,m)$, there is a set of whitened value sequence $b_i^{(0)}=\{p_i^{(0)}(1), b_i^{(0)}(2)..., b_i^{(0)}(N)\}$, and $b_i^{(1)}$ is obtained after one accumulation for $b_i^{(0)}$, and a GM(1, 1,) prediction model is built with the data $b_i^{(1)}$, the prediction value can be obtained through the model $\hat{b}_i^{(0)}(k)(k<N)$. Therefore, by finding the linear programming value in $\otimes(A)X \le \begin{bmatrix} \hat{b}_1^{(0)}(k) \\ \hat{b}_2^{(0)}(k) \\ \vdots \\ \hat{b}_m^{(0)}(k) \end{bmatrix}$ and taking different values under the conditions of $k>N$, various planning or optimization values for the future development moments can be obtained, and therefore, the existing conditions can be obtained. the optimal structure under the existing conditions and its development trend.

3. Optimization analysis of ecological landscape water body network based on linear programming

3.1. Results of water body network optimization

This paper introduces the linear planning model into the structural adjustment of each type of element of ecological landscape water body network, and constructs a scientific and reasonable model to realize the optimization of green space element configuration through reasonable setting of variables.

According to the current situation of the ecological landscape water body network in X city, and combining the actual situation, after considering the operability of the variable scheme, a total of 10 variables were set, the area of water body landscape in urban construction land X_1, the area of water body plants X_2, the area of irrigation grassland X_3, the area of water domain X_4, cultivated land X_5, the area of dense forest land within non-construction land X_6, the area of open forest land X_7, the area of irrigation grassland X_8, the area of water domain X_9, the area of other land X_{10} The unit of area is standardized as hm^2.

Combining the natural, economic and social development of X city, with the objective of maximizing the ecosystem and economic benefits as much as possible, an objective function is established, and the relevant influencing factors are used as constraints to explore the optimization scheme for the optimization of the elemental allocation of the ecological landscape water body network.

3.1.1. Optimization of ecological services in water bodies. The results of the optimization carried out under the objective of maximizing ecosystem services are shown in Table 1, under the maximization of ecosystem services, the final increase of 334.198 hectares of the area of water body landscape construction and 99.121 hectares of the area of water body plants, and the decrease of 432.03 hectares of irrigation and grassland. The area of water body and other land area increased less, 0.110 and 0.920 ha respectively. After the optimization, the ecological services of water bodies increased from 75,691.07 to 81,267.34, and the final ecological services of water bodies increased by 5,576.27, or about 7.4%.

Table 1. Maximize optimization of ecosystem services

Urban type		Equivalent value of ecosystem services	Status area	Optimized back product	Change
Construction land	X1	73.11	289.89	624.088	334.198
	X2	65.94	367.3	466.4214	99.1210
	X3	58.78	435.43	3.42	-432.010
	X4	70.04	77.18	77.29	0.110
	X5	32.15	0	0	0
Unconstructed land	X6	118.34	0	0	0
	X7	130.53	0	0	0
	X8	88.72	0	0	0
	X9	96.46	0	0	0
	X10	0.13	1.25	2.17	0.920
Total			1171.050	1173.389	2.3394
Ecosystem service			75691.07	81267.34	5576.27

A comprehensive analysis of the ecological landscape water body network in City X shows that even if all the cover types are turned into ecological landscape water body construction, it is still difficult to achieve the optimal ecosystem service equivalent requirements, i.e., the total amount of ecological water body space is seriously deficient, which is closely related to the construction density, cultural history, etc. in City X. Therefore, for the target conditions of ecosystem services, City X, in addition to the adjustment of the ratio structure of elements, also needs to integrate external resources, i.e., to utilize a variety of potential resources that can provide ecosystem services to fully compensate for the region.

3.1.2. Optimization of water body economics. According to the logic of constraint formulation, the results of optimization with the objective of maximizing economic benefits are shown in Table 2. Under the maximization of economic benefits, the area of water body landscape construction, the area of water body plants, the area of water body, the area of cultivated land and the area of other land increased by 281.630, 35.120, 17.940, 63.240, and 9.100 hectares, respectively, and the area of irrigated grassland decreased by 334.952 hectares. After optimization, the size of the water body economy was increased from 18695.42 to 20468.88 and the final size of the water body economy was increased by 1773.46 or about 9.5%.

Table 2. Maximization of economic benefits

Urban type		Economic benefit equivalent	Status area	Optimized back product	Change
Construction land	X1	77.48	289.89	571.52	281.630
	X2	68.2	367.3	402.42	35.120
	X3	61.04	435.43	100.478	-334.952
	X4	71.3	77.18	95.12	17.940
	X5	33.41	0	63.24	63.240
Unconstructed land	X6	119.6	0	0	0
	X7	131.79	0	0	0
	X8	89.98	0	0	0
	X9	97.72	0	0	0
	X10	1.39	1.25	10.35	9.100
Total			1171.05	1243.128	72.078
Economic benefit scale			18695.42	20468.88	1773.46

Comprehensively analyzing the scale of economic benefits in City X, it can be seen that the existing ecological water body network design can basically meet the requirements of economic benefits by reasonably adjusting the ratio structure between various elements. Therefore, in order to maximize the economic benefits of ecological landscape water body network design in City X, it is necessary to firstly carry out the macro-ratio control of each type of element, and then carry out the improvement of element quality and the integration of potential resources.

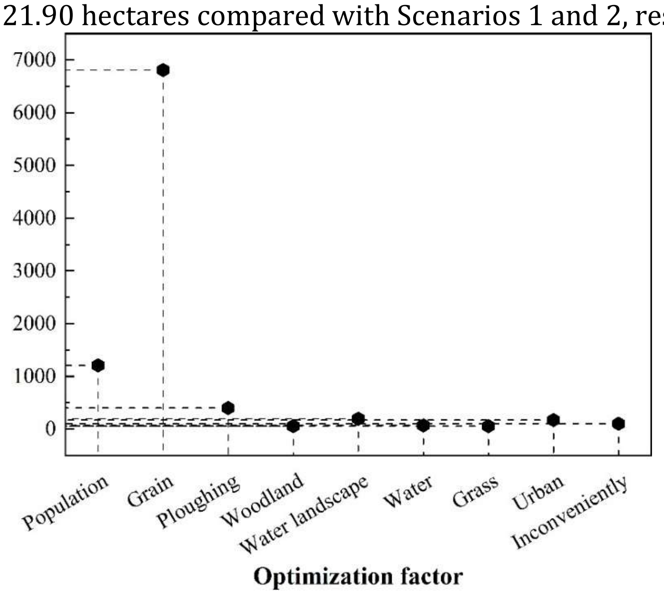
3.2. Comparison of Optimization Options for Ecological Landscape Waterbody Networks

As the benefit coefficient and constraint coefficient in the gray linear planning model are interval gray numbers, they can be planned according to the lower limit, the upper limit, and also according to the interval value, which makes the planning flexible, elastic, and able to adapt to the development and change of the situation. This paper combines the future development trend and optimization principle of X city, after considering the requirements of ecosystem and economic benefit maximization development goal respectively, comprehensively consider the real demand of optimization of ecological landscape water body network in X city, based on the support of LINGO 6.0 software, on-line operation, and optimization results of repeated debugging, to obtain three practical and feasible optimization schemes, different optimization simulation methods as shown in Fig. 3.

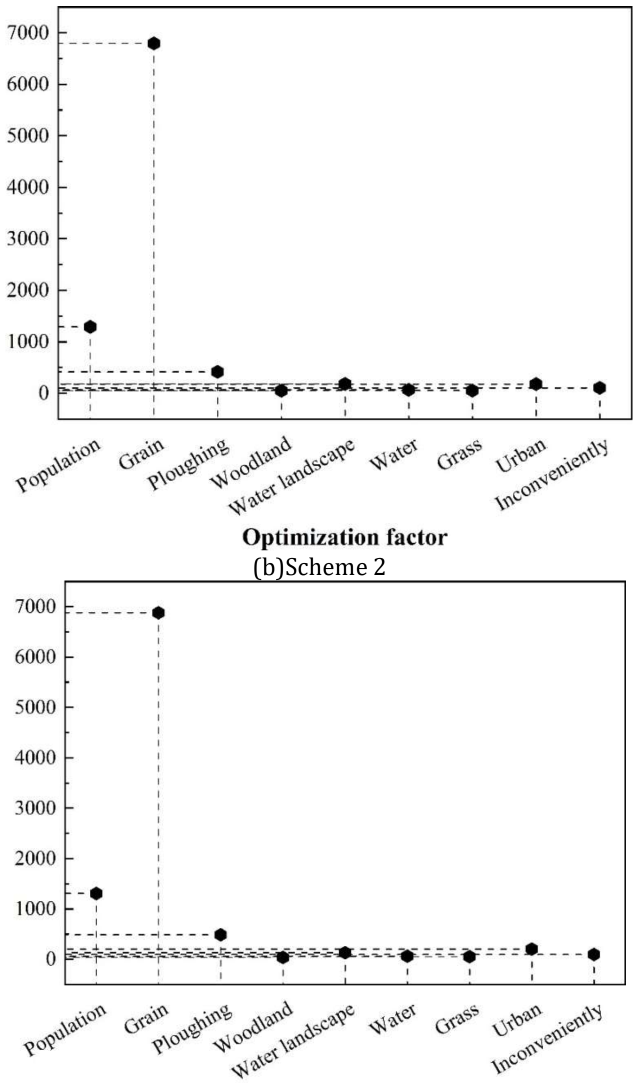
Scheme 1 is the ecological landscape water body network optimization simulation scheme under the situation of attaching great importance to ecological benefits, a large number of retired farmland and water and forest, and scientific and technological progress to make rapid growth in economic benefits. The utilization rate of the city is high, and in this scenario, the area of cultivated land is 398.12 hectares, the urban land occupation area is lower at 170.03 hectares, and the ecological water body scenery is greatly improved at 195.5 hectares. This scenario is a more ideal optimized structure with faster economic development and higher ecological environment quality, and at the same time, it can improve people's living and living standards.

Scenario 2 is an optimization method under the comprehensive consideration of ecological and economic benefits, and its cultivated land area is improved by 17.29 ha compared with Scenario 1, and the ecological water landscape is reduced by 13.88 ha. It is a relatively balanced optimization scheme, and its realization is less difficult.

Method 3 is a simulation scenario under the full attention to economic benefits, and in this scenario, the cultivated land area is greatly enhanced, and the ecological water body landscape construction response is reduced. At the same time, the development of difficult-to-use land is increased, and the difficult-to-use land is reduced to 95.33 hectares, and the urban land exceeds 200.35 hectares, which is upgraded by 30.32 and 21.90 hectares compared with Scenarios 1 and 2, respectively.



(a)Scheme 1



(c)Scheme 3

Fig. 3. Different optimization simulation methods

The optimized scenarios of landscape quantitative structure of Scenarios 1, 2 and 3 were imported into the objective function, and the economic value and ecosystem service value of each scenario landscape were calculated respectively. A comparison of the ecological and economic values of the optimization scenarios is shown in Fig. 4. The economic and ecological values of Scenario 1 of the optimization of the ecological landscape water body network in City X are 315.2 billion yuan and 75.2 billion yuan, respectively, which are lower than Scenarios 2 and 3 by 60.7 billion yuan and 154.3 billion yuan, respectively, but their ecological values are significantly higher. Scenario 2 is the scenario that integrates the economic and ecological values, and therefore, its economic and ecological values are in the middle of the range, at \$375.9 billion and \$65.3 billion, respectively. Scenario 3 focuses on economic benefits, and thus has a higher economic value of 469.5 billion dollars. Based on linear planning, this paper proposes three practical and feasible specific schemes for optimizing the design of ecological landscape water body network, which can be selected according to different needs and help to improve the ecological environment quality of X city.

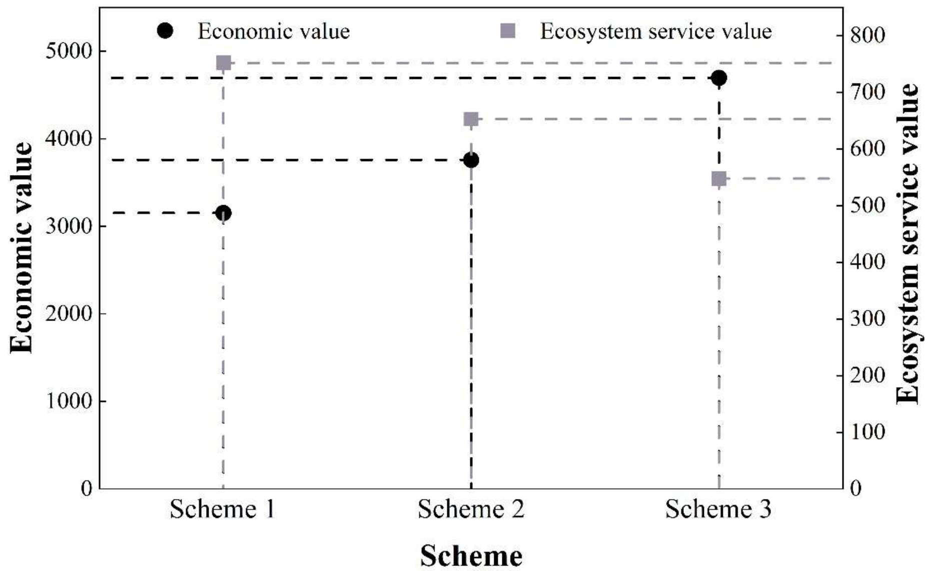


Fig. 4. The ecological and economic value of the optimization scheme

4. Conclusion

Ecological landscape water body network is an important part of the urban ecosystem, which is an important element to maintain the stability of the ecosystem and high environmental quality. The optimal design of ecological landscape water body network can not only bring benign development for the ecological environment system, but also bring certain benefits for the economic development of the city. Based on this, this paper uses linear programming to optimize the design of the ecological landscape water body network in City X. The design of the water body ecosystem services and the economic benefits of the water body are discussed in the following sections.

Under the objective of maximizing both ecosystem services and economic benefits of water bodies, the ecosystem service scale of City X is improved by 5576.27, which is an increase of about 7.4%. The scale of economic benefits increased by 1773.46, an increase of about 9.5% The current status of the ecological landscape water body network in City X is poor, and for the target conditions of ecosystem services, the ecosystem services of City X are improved, but it is still difficult to achieve the optimal ecological service equivalent requirements. And the existing ecological water body network design in City X can basically meet the requirements of economic benefits by reasonably adjusting the proportion structure between each element. Therefore, this paper combines the current situation of City X, comprehensively considers the realistic demand and the feasibility of the method on the ground, and proposes three optimization schemes with ecological benefits, economic benefits and comprehensive benefits as the entry point. The research and optimization results of the three schemes are as follows:

Scenario 1 pays full attention to the ecological benefits, with a lower urban land occupation area of 170.03 ha, and the ecological water body view is greatly improved to 195.5 ha. The economic value and ecological value are 315.2 billion yuan and 75.2 billion yuan respectively, which is a more ideal optimized structure with ecological benefit tendency.

Scheme 2 is an optimization method under the comprehensive consideration of ecological and economic benefits, its cultivated land area is improved by 17.29 ha compared with Scheme 1, but the ecological water body landscape is reduced by 13.88 ha, and its economic and ecological values are 375.9 billion yuan and 65.3 billion yuan, which is a more suitable optimization method for the current situation of the development of X city, and the operability and implementation are higher.

Method 3 pays more attention to economic benefits, and it mainly focuses on hard-to-use land, which is vigorously developed, and the hard-to-use land is reduced to 95.33 hectares in order to realize the increase of urban land area. Its economic value is higher at 469.5 billion dollars, but the ecological value is reduced to 54.8 billion dollars. Option 3 exchanges ecological value for economic value, which gives a large increase in economic value, but is not a long-term development strategy and should be considered carefully.

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