J. COMBIN. MATH. COMBIN. COMPUT. 127a (2025) 985–1003

Journal of Combinatorial Mathematics
and Combinatorial Computing
www.combinatorialpress.com/jcmcc

Combinatorial Press

Design and Application of Garden Water Management Models Incorporating Internet of Things (IoT) Technology

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ABSTRACT

Garden is an important support for regional economic development, but also an important support for regional ecological environmental protection, the rational allocation of water resources in the garden is one of the effective ways to solve the problem of water shortage. This paper takes the Internet of things, digital twin as the technical basis, uses the multi-objective optimisation algorithm to construct the water resource management model of the garden area, and uses the artificial fish swarm algorithm to solve the model. By constructing a digital twin irrigation district water resources scheduling management platform, the water resources elements of the garden area are comprehensively monitored and sensed, and the intelligent simulation of the water resources allocation management process and decision-making scheme evaluation and optimisation are achieved, so as to enhance the intelligent and refined management level of water resources scheduling of the garden area, and comprehensively realise the saving and intensive use of water resources. Taking X garden area as a research case, the water resources management model finally derives the optimal water resources allocation scheme under 50%, 75% and 90% in each planning year, which provides support for the efficient use of water resources in X garden area.

Keywords: internet of things, digital twin, multi-objective optimisation, water resource management model, artificial fish swarm algorithm

1. Introduction

Water supply for plants is an important maintenance task during the construction and implementation of landscaping projects. China is a per capita water scarce country, the development of water-saving irrigation is imperative [1-2]. The inland areas of Northwest China have long been in arid and semi-arid climatic environments, affected by natural conditions, with serious water shortage, and the southeast coastal areas, despite abundant rainfall, lack of water-saving thinking and focus more on drainage projects [3-4]. In the context of natural resource constraints superimposed on human factors, the prevalence of water-saving irrigation projects in urban landscaping in China needs to be further improved. Water is a carrier of

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Received 25 September 2024; Revised 18 December 2024; Accepted 03 January 2024; Published Online 15 April 2025.
DOI: 10.61091/jcmcc127a-057

pollutant transport, and diffuse irrigation can easily lead to groundwater and river surface pollution, and the increase of irrigation will promote the emission of carbon dioxide in the soil [5-6].

Since the ‘dual-carbon’ goal was proposed, emission reduction has become a major national decision-making deployment. Effective implementation of water-saving irrigation in urban gardens will become one of the key paths to implement the national carbon peak and carbon neutral targets. At present, sustained economic benefits are mainly reflected in agriculture, and garden plants are mainly ornamental and cannot produce long-term economic returns, so compared with agriculture, water-saving irrigation projects are less used in urban gardening [7-9]. From the current point of view, most of the urban landscape greening using artificial or mechanical irrigation, irrigation method is relatively crude, often relying on sprinklers to carry out large water diffusion irrigation, which results in poor timeliness of irrigation, low uniformity, insufficient or excessive irrigation water, easy to lead to the growth and development of landscape plants is hindered, and even dead seedlings phenomenon [10-12]. The existing irrigation machinery as well as the irrigation project intelligence level is low, labour-consuming and time-consuming, increasing the maintenance cost, part of the problem of poor equipment quality and low irrigation efficiency. There are some differences in the water requirements of different landscape plants, for example, lawns require a higher amount of irrigation water, while trees and shrubs require a lower amount of irrigation water [13-14]. At present, people's requirements for the ornamental function of landscape plants are increasing, and the proportion of lawn is also increasing, and many areas will change trees and shrubs to lawn, which substantially increases the amount of irrigation water. In addition, some regions set crops with high and low water demand in the same area, resulting in lower water use efficiency [15-16]. There are also regions that have introduced a large number of tropical tree species or high water-demanding tree species, which has significantly increased the cost of water use. In the operation of urban gardens, water not only plays the role of irrigation, but also plays the role of landscaping from time to time [17-18]. Many urban gardens have fountains, artificial waterfalls and other landscape resources, large-scale irrigation of garden plants is also often used as a more spectacular ornamental elements for people to enjoy. However, most of the water used in these landscapes comes from the municipal water system, i.e., tap water, which results in a significant increase in water costs. After the water is used, this water is discharged directly into the downspout and is not recycled into the irrigation system, thus further leading to water wastage and increased water costs [19-20].

With the development of urbanisation, the scale of urban greening is constantly expanding, at the same time, the management of urban landscaping industry also needs to keep pace with the times, and the traditional way of landscaping management has been unable to fully meet the requirements of high-speed development of urban greening and high-quality urban life. The promotion of urban landscaping informatisation has become a necessary path for the modernisation of the landscaping industry in the new era [21-22].

This paper constructs a water resource management model for the garden area based on the balance between supply and demand of water resources in the park, with the maximisation of economic, social and ecological benefits as the optimisation objective, and based on the multi-objective optimisation algorithm. The artificial fish swarm algorithm is used to solve the multi-objective optimisation model, and the optimal mode of joint regulation of water resources in different level years in the garden area is studied. Based on the Internet of Things and digital twin technology, the resource management model is embedded to construct a water resources dispatching management platform for the garden area. Through the cyclic calculation and analysis of forward previewing dispatching impacts and reverse extrapolating dispatching scheme, the water resources management scheme is iteratively optimised until it meets the water allocation plan of the garden area. Comprehensive monitoring and sensing of water resources elements in the garden area to achieve intelligent management of water resources scheduling and management process.

2. Modelling of water resources management in garden areas

2.1. *Modelling ideas*

Water resources management model is based on the establishment of the regional water resources cycle and regulation of balance equations, establish the basic calculation unit, water supply and use of water resources consumption and discharge balance equation, water conservancy project scheduling balance equation, water resources water supply capacity, as well as other constraints on the equation for the constraints, the selection of a reasonable objective function to build the mathematical planning model.

The optimal allocation of water resources in the garden area refers to the principles of effectiveness, fairness and sustainability in accordance with the water demand requirements of the garden area. Using a variety of engineering and non-engineering measures, in accordance with the laws of the market economy and resource allocation guidelines, through the reasonable suppression of demand, to ensure effective supply, maintenance and improvement of ecological environment quality and other means and measures. Artificial dynamic deployment of a variety of available water sources between regions and various water-using sectors to improve the allocation efficiency of water resources in the garden area.

Limited to the collection of data, the lack of socio-economic benefits of the garden area of the parameter data, while taking into account the garden area, the amount of water resources available or the degree of water shortages in the water sector, to some extent, can indirectly reflect the socio-economic benefits of the situation, this paper explores the garden area water resources management model to water as the object of the study, a water sector has a number of sources of water supply water supply, the amount of water available to the water resource Optimising the amount of water supplied in each month of the year.

In order to realise the full use of water resources, with the objective of maximising economic benefits (objective 1), social benefits (objective 2) and ecological benefits (objective 3), a water management model for the garden area is established by taking the amount of water supplied by different water supply sources to the sector in each water use period as a decision-making variable, and using the month as the calculation period.

2.2. *Objective function*

This study establishes a model based on the appropriate development scale and layout of garden area use under water resource management, under the constraints of available water consumption, the maximum garden area development scale that can be supported as an indicator to quantitatively express the support of water resources for the development of garden scenic spots, and the optimal economic, social, and ecological benefits as the goal of solving the adaptive scale of the development of the garden area and the plant plant planting structure as the goal [23].

For this study, the multi-objective optimisation model established is as follows.

2.2.1. Economic efficiency objectives. In this paper, the maximisation of the economic benefits of the garden area, as the objective 1 of the management optimisation, establishes a multi-objective optimisation function:

$$f_1(x) = \max\left\{\sum_{i=1}^{I}\sum_{j=1}^{J}\left[\left(\rho^{\pm}_{AVG,i}\cdot IRRIG_{i,j}\cdot Y_{\max,j} - \sum C\right)\cdot x_{i,j}\right] - C^{\pm}_{AVG,i}\cdot\sum_{j=1}^{J}\left(IRRIG_{i,j}\cdot x_{i,j}\right)/\eta_j\right\} \tag{1}$$

$$\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j} = \lambda^* \cdot X \tag{2}$$

$$\Delta x = \left(1-\lambda^*\right)\cdot X \tag{3}$$

where $x_{i,j}$ is the area $\left(hm^2\right)$ of different crop types i irrigated using different water sources j, $i=1,2,3\ldots$ is the crop type, and $j=1,2,3\ldots$ is the order of water sources. $\rho_{AVG,i}^{\pm}$ represents the average market price of different crops (yuan/ kg), $C_{AVG,j}^{\pm}$ represents the cost of water from different sources (yuan/ m^3). $Y_{\max,j}$ represents the maximum yield of crop i, $\left(kg/hm^2\right)$, $IRRIG_{i,\ j}$ represents the amount of irrigation water for different crops i using different water sources j respectively, $\left(m^3/hm^2\right)$, η_j is the water use efficiency of different water sources. $\sum C$ is the other operating costs per unit area (yuan), including the sum of transport costs, agricultural irrigation machinery costs, crop fertiliser costs, and labour costs. X is the total developed area $\left(hm^2\right)$ of the garden area, which also includes road area, forest network area and other areas, etc. λ^* is the coefficient of arable land (%), and Δx is the sum $\left(hm^2\right)$ of road area, forest network area and others.

2.2.2. Social benefit objectives. Social benefits are often difficult to measure directly, and commonly used indicators related to social stability and residents' living standards include per capita arable land, per capita road area, per capita disposable income, and the number of labour force resettlement. In this study, the social benefits brought to the region through the development and use of the garden area are measured using the labour force resettlement benefits, as well as the rural road construction benefits.

In this paper, the objective of maximising the social benefits of the garden area is taken as the objective 2 of management optimisation, and a multi-objective optimisation function is established:

$$f_2(x)=\max\left\{\left[\left(\sum_{j=1}^{J}\sum_{i=1}^{I}x_{i,j}/\phi_{Labor}\right)\cdot\tau\right]+\left(1-\lambda^*\right)\cdot X\cdot\varepsilon\right\} \tag{4}$$

Where ϕ_{Labar} is the number of labourers that can be accommodated per unit area (persons/ hm^2), of which the number of persons that can be accommodated in cash crops and food crops is about 5 persons/ha, and the number of persons that can be accommodated in forage crops is 2 persons/ha. τ is the disposable income of people engaged in agriculture (yuan), and ε is the efficiency coefficient of road construction (ten thousand yuan/ hm^2).

2.2.3. Eco-efficiency objectives. The steps for calculating the ecological service value of the garden area are as follows:

Set the total area of the garden area as $S_{General}$, the optimal forest cover as R, the area of forested land required by the optimal forest cover as S_{Lynn}, the actual area of forested land as $S_{\mathrm{Re}al}$, the area of i types of land as S_k, the green equivalent as EGE_k, and k represents the type of land as $(k=1,2,3\ldots)$, then:

1) Determine the optimal forest cover R in the garden area with the formula:

$$R=\frac{P\times S_k}{W\times S_{General}}\times 100\% \tag{5}$$

Among them, P is the maximum daily precipitation in the year $\left(t/hm^2\right)$, S_i is the land area of the i type $\left(hm^2\right)$, and W is the saturated water storage capacity of forest soil per unit area $\left(t/hm^2\right)$.

2) Calculate the area of forest corresponding to the optimal forest cover R. The forest corresponds to a green equivalent of 1. Then:

$$S_{Lynn}=S_{General}\times R \tag{6}$$

3) Calculate the ecological green equivalent of the actual forest land in the region X_{Lynn}:

$$X_{Lynn} = \frac{S_{\mathrm{Re}al}}{S_{Lynn}} \tag{7}$$

4) Calculate the total ecological green equivalent of the region $X_{General}$:

$$X_{General} = X_{Lynn} + \sum_{i=1}^{k} \left[\frac{S_k \times EGE_k}{S_{Lynn}} \times 100\% \right] \tag{8}$$

The value of ecological services is calculated as:

$$ESV_k = ESV_{Lynn} \times EGE_k \times S_k \tag{9}$$

At the same time, the total ecological value of the entire garden area calculated using the equivalent method. Here, in order to highlight the role of the development and utilisation of the garden area in improving the ecological environment, the method of subtracting the original local ecological value from the total ecological value of the garden area is adopted, and only the new ecological benefits generated by the development and utilisation of the garden area are used to characterise the ecological benefits.

Combined with the above calculation method of ecological asset value based on ecological green equivalent, the objective of ecological benefit is to maximise the value added of ecological assets in the garden area, and the objective function is established as follows:

$$f_3 = \max\{\Delta ESV\} = \max\left\{\sum_{k=1}^{K}\left(ESV_k' - ESV_k\right)\right\} \tag{10}$$

Combined with a formula for calculating the value of ecological assets based on ecological green equivalent, this can be translated into:

$$f_3(x) = \sum_{k=1}^{K}\left\{\left[\sum_{k=1}^{K}\left(\frac{\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j}}{S_{Lynn}} \cdot EGE_k\right) \cdot 100\%\right] \times V_{Lynn} \times \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I} x_{i,j}\right\} \tag{11}$$

Where k represents the type of site $(k = 1, 2, 3\ldots)$, the area of forested land in the region required by the optimal forest cover is S_{Lynn} , the green equivalent is EGE_k , V_{Lynn} represents the ecological asset value per unit area of the forest system, and the other symbols are as in the previous section.

2.3. *Constraints*

2.3.1. Water constraints. The amount of water available in the garden area is an important water resource input condition for the model, and is a decisive factor in constraining the scale of landscape vegetation in the garden area. The amount of water resources available in the garden area is not only affected by the local natural water resources conditions, but also controlled by the construction of local water supply projects and the implementation of water resources management policies. Therefore, when considering the available water resources in the garden area, it is necessary to fully compare the relationship between the available water resources in the area, the water supply capacity of water conservancy projects and the total water consumption control index under the "strictest water resources management system". By quantifying the interval of water availability, water supply availability and target limitations, the water availability of the garden area is obtained after deducting the normal water consumption of each water sector.

According to the principle of interval quantification of water availability in the garden area, the total amount of new irrigation water in the garden area shall not exceed the minimum value of all indicators in the interval. In other words, the value of the indicator after deducting the water consumption of other sectors is taken as the upper limit of the water consumption in the garden area:

$$\begin{aligned}\sum Q_{sa} &= \sum_{i=1}^{i}\sum_{j=1}^{j} IRRIG_{i,j} \cdot x_{i,j} \\ &\leq \min\left[\sum_{j=1}^{I}\left(Q_T - \Delta Q_j\right), Q_\sigma - \sum_{j=1}^{J}\Delta Q_j, Q_R - \sum_{j=1}^{J}\Delta Q_j\right]\end{aligned} \tag{12}$$

Among them, $\sum Q_{sa}$ is the total amount of water used in the garden area $\left(m^3\right)$, $\sum_{i=1}^{i}\sum_{j=1}^{j} IRRIG_{i,j}$ is the amount of water used for irrigation per unit area (m^3 /mu). Q_T is the total amount of water resources available from different sources $\left(m^3\right)$, Q_G is the total amount of water resources available from water conservancy projects $\left(m^3\right)$, ΔQ_j is the total amount of water demanded by other water-using industries $\left(m^3\right)$.

2.3.2. Water use factor constraints. The irrigation water utilisation factor for the garden area is controlled in accordance with the strictest water resource management system and regional water resource planning. To wit:

$$\eta_j \geq \max\left[\eta_R, \eta_R'\right] \tag{13}$$

Where η_R and η_R' are the most stringent water resources management system, and the irrigation water use efficiency constraints of the regional water resources planning and control objectives, respectively.

2.4. *Model solving*

The objective function is dimensionless:

$$e_p\left(x\right) = \frac{f_p\left(x\right) - \left(f_p^{\ 0}\right)}{f_p^* - f_p^{\ 0}} \tag{14}$$

Where $e_p\left(x\right)$ is the objective function after normalisation of the p nd objective, f_p^0 is the worst value of the p th objective and f_p^* is the optimal value of the p th objective.

Construct an auxiliary function to convert the multi-objective function into a single-objective function:

$$F\left(x\right) = \sum_{p=1}^{P} \omega_p e_p\left(x\right) \tag{15}$$

where $F\left(x\right)$ is the auxiliary function and ω_p is the weight coefficient corresponding to the p rd objective.

2.4.1. Solution algorithms. The optimisation of water resources in the garden area has many factors, large scale, wide influence and great difficulty, and the conventional traditional methods have some limitations in the calculation speed and sensitivity of the initial value, coupled with the influence of the decision-maker's preference, which cannot solve the problem well. Intelligent optimisation algorithm - artificial fish schooling algorithm has the advantages of low requirements on initial value and parameter setting, only need to compare the value of the objective function. Therefore, this paper selects the artificial fish school algorithm to solve the model.

Artificial Fish Swarming Algorithm (AFSA) is a population intelligence optimization algorithm based on the foraging behaviour of fish. The three main behaviours of the algorithm are [24]:

1) Foraging behaviour. Generally fish swim freely in the water randomly and when they find food then they swim in the direction where there is more food. In the optimisation algorithm it is an iterative way of moving towards the better direction.

It is expressed in mathematical expression as:

$If\left(Y_i < Y_j\right)$:

$$x_{inext} = x_i + random(step)\left(x_i - x_j\right) / \left\| x_i - x_j \right\| \tag{16}$$

$If\left(Y_i > Y_j\right)$:

$$x_{inext} = x_i + random(step) \tag{17}$$

where $random(step) = rand(\ ) \times step$, denotes the random number between $[0, step]$, and Y_i and Y_j are the food concentrations corresponding to states X_i and X_j.

2) Swarming behaviour. Artificial fish clustering behaviour is that the artificial fish moves to the centre of the partner that is superior to itself within its own perception range in order to achieve the purpose of seeking superiority.

The mathematical formula is expressed as follows:

$$x_{inext} = x_i + random(step)\left(x_c - x_i\right) / \left\| x_c - x_i \right\| \tag{18}$$

3) Tail chasing behaviour. That is, a kind of chasing behaviour towards the nearest most active person, which can be understood as the process of advancing towards the nearby optimal partner in the optimality seeking algorithm. Tail chasing behaviour helps to move rapidly in a certain extreme direction, accelerating the speed of optimality search.

The mathematical formula is expressed as follows:

$$x_{inext} = x_i + random(step)\left(x_{\max} - x_i\right) / \left\| x_{\max} - x_i \right\| \tag{19}$$

2.4.2. Solution process. The process of solving the water resource management model for the garden area based on the artificial fish school algorithm is shown in Fig. 1:

Step1. determine the size of the fish school, set the artificial fish perception distance $visual$, step length $step$, the number of attempts $try\ mumber$.

Step2. Set the variables and related parameters to achieve the control of constraints, such as the amount of water stored in the reservoir of the forest park, the amount of groundwater that can be supplied to irrigation after deducting the domestic, industrial and ecological water supply, and the upper and lower limits of the irrigation water demand in each calculation period.

Step3: Generate N artificial fish randomly under the constraints to get the initial fish individuals.

Step4: Discriminate the constraints of water resources carrying capacity of the initial fish group, eliminate the artificial fish that do not meet the conditions and replenish the new artificial fish that meet the constraints in a timely manner.

Step5: Filter the artificial fish that meet the constraints to get the optimal artificial fish state and objective function value, and assign them to the bulletin board.

Step6. Individual artificial fish update themselves through the behaviours of swarming, tail chasing, foraging, etc. The constraints are discriminated after each occurrence of the behaviours; swarming behaviour leads to violation of the constraints, then foraging behaviour is carried out; foraging behaviour fails, then random behaviours are adopted; tail chasing behaviours are similar to this one.

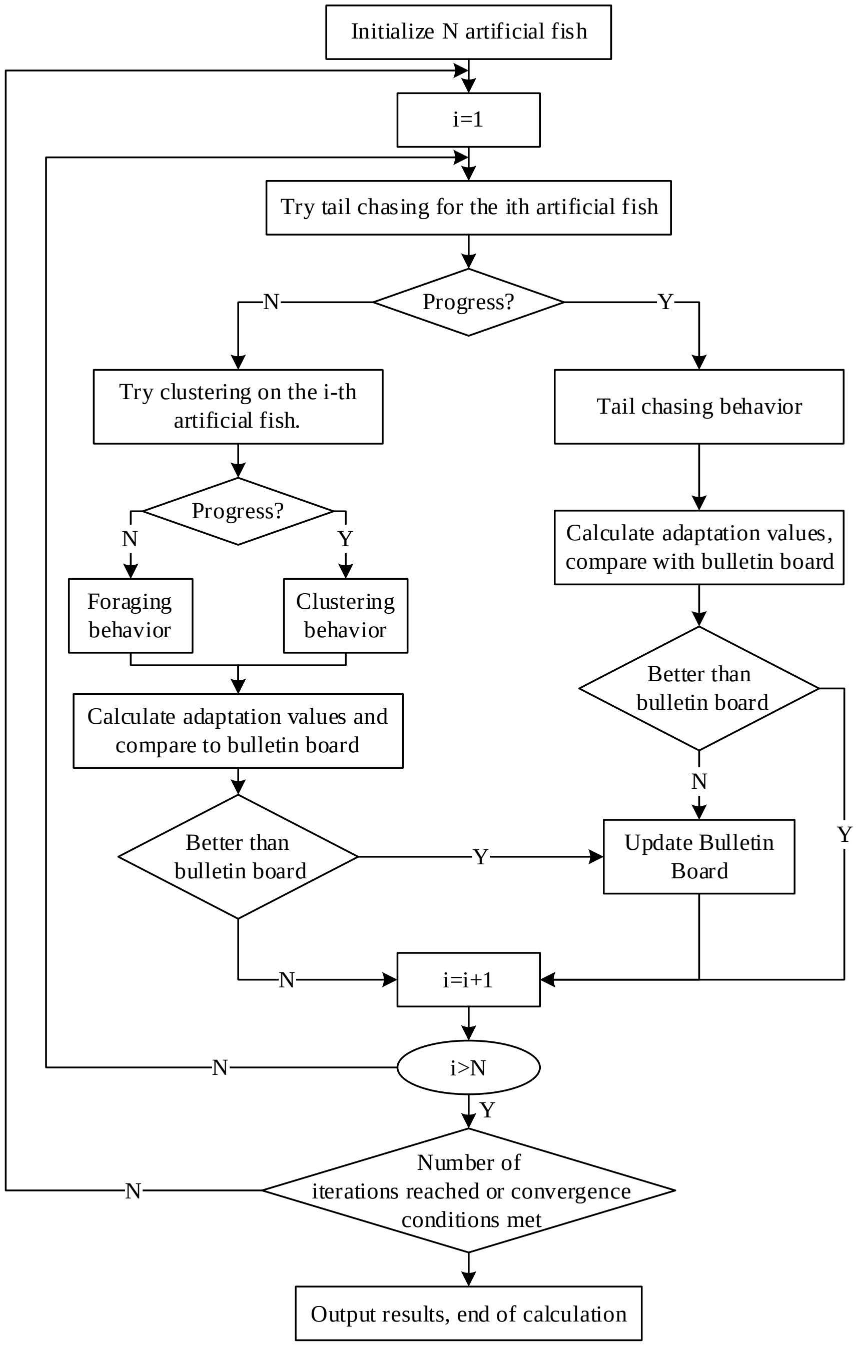


Fig. 1. The flow chart of artificial fish swarm algorithm

Step7. At the end of each update the new fish population is screened to get the optimal artificial fish state and the bulletin board is updated.

Step8. The algorithm ends when the optimal solution on the bulletin board reaches within the satisfactory error bound. Otherwise it will continue as Step6 until the optimal solution with satisfactory error is obtained.

3. Key technologies for water resource management in IoT garden areas

The combination of IoT, digital twin technology and water resource management model provides strong support for water resource refinement management and scheduling intelligent decision-making in the garden area. Internet of Things (IoT) technology brings together a large amount of real-time data of physical entities in the irrigation area by connecting multiple types of sensing devices. The digital twin technology carries out digital expression and visualisation of all elements of the management scope of the garden area, and continuously updates the scene state of the digital twin based on real-time sensory data. Combined with the water resources management model for scheduling simulation simulation deduction, forward preview of the key cross-section water level and gate overflow in different scenarios of the state and changes. Based on the analysis results of the water resource management model, dynamic iteration optimises the dispatching scheme. Finally, the optimised scheduling decision scheme is used as a scheduling plan to remotely manipulate the gate opening through the Internet of Things (IoT), and feed back the gate opening, water level, flow rate and other state changes to the digital twin scenario again to realise the bidirectional synergistic mutual feedback between the digital twin and the physical entity.

3.1. Real-time sensing and control system of water resources in the garden area

This paper focuses on the needs of water resources scheduling and management business in the garden area, and builds an IOT sensing and control system for the irrigation area that integrates the capabilities of equipment management, connection switching, protocol parsing, parameter adjustment, and health checking. Adaptation, integration of many types of basic sensing equipment, collection, management of many types of sensing data, through the Internet of Things network to achieve efficient and safe transmission of data for real-time sensing irrigation district water resources elements state, equipment and facilities remote intelligent control to provide support, garden area water resources real-time sensing and control system structure as shown in Figure 2 [25].

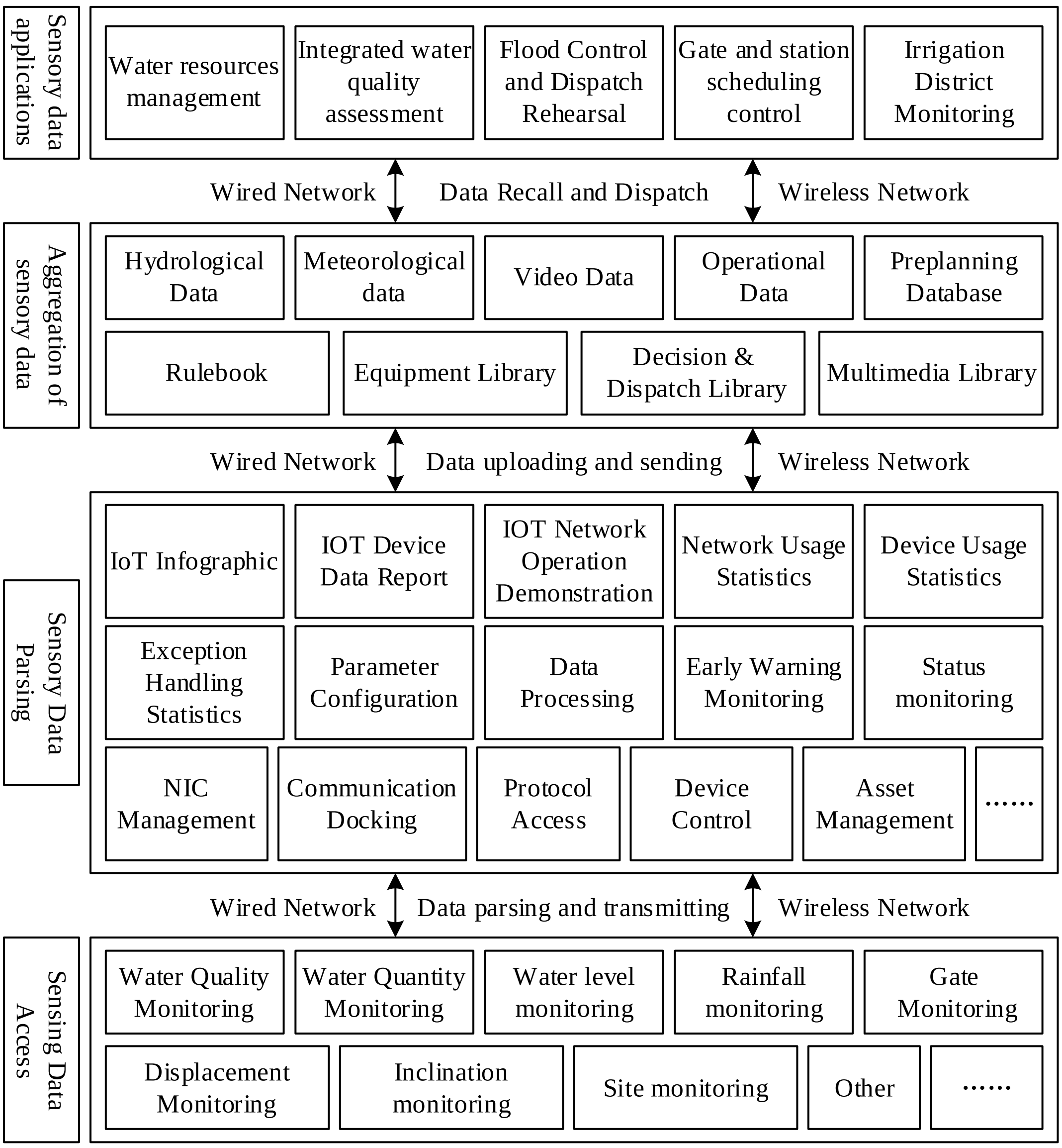


Fig. 2. Real-time sensing and control system of water conservancy in garden areas

It can be seen that the real-time sensing and control system of water resources in the garden area mainly includes:

1) Sensing data access layer. Through a variety of wired and wireless transmission methods will garden area water quality monitoring station, water quantity monitoring station, water level monitoring station, and other water conservancy sensory equipment access to the Internet of things. And the rainfall, moisture, water level, flow, water quality, engineering safety and other collected data convergence to the perception data analysis layer.

2) Perception Data Analysis Layer. According to the actual situation of the garden area, it achieves integrated supervision of water conservancy sensing equipment in the region, and at the same time serves as a pivotal processing platform between the data centre, business system and controlled equipment, supporting the basic remote control of the business system on most of the equipment.

3) Perception data convergence layer. As a centre for convergence and storage of perceptual data such as hydrology, meteorology, video, equipment status, etc., it provides the required data directly to the business systems or functions of the application layer through interfaces.

4) Perception Data Application Layer. Based on the large amount of data provided by the perceptual data aggregation layer, it carries out water resources management, comprehensive evaluation of water quality, flood control scheduling preview, gate and station scheduling control, normal monitoring of the garden area, and other water conservancy business applications.

3.2. Management of water scheduling previews for garden areas

In this paper, we iteratively optimise the water resource management scheme through a cyclic computational analysis of forward previewing the impact of scheduling - reverse extrapolating the scheduling scheme until it meets the water allocation plan of the garden area.

3.2.1. Positive preview scheduling impacts. With the direction of serving water resources scheduling practice in the garden area, it comprehensively couples water project scheduling application information and hydrodynamic model, positively previews the impacts of water resources scheduling programmes, and timely discovers the problems of scheduling application programmes. The main contents include:

1) Hydrodynamics calculation. The non-constant flow in the canal system is described by the St. Venant system of equations, and the flow in the inverted siphon is pressurised, which is described by the basic equation of non-constant flow in low-pressure pipelines:

$$\begin{cases} \dfrac{\partial(\rho Q)}{\partial x}+\dfrac{\partial(\rho F)}{\partial t}+\rho q=0 \\ \dfrac{\partial H}{\partial x}+\dfrac{u}{g}\dfrac{\partial u}{\partial x}+\dfrac{\partial u}{g\partial t}+\dfrac{u^2}{c^2R}-\dfrac{2uq}{gF}=0 \end{cases} \tag{20}$$

Among them, x for the distance, t for the time, ρ for the density of the water body, Q for the overflow cross-section flow, F for the overflow cross-section area, H for the head of the pressure tube, u for the flow rate, c for the Xie Cai coefficient, R for the wet week, q for the unit of the length of the canal section out of the flow.

Restraint gates, sub-retreat sluice gate over the gate water flow pattern due to the relative openness of the gate e/H and different, can be divided into hole flow, weir flow and holes and weir flow alternately, the flow rate is calculated using the following formula:

$$Q=\begin{cases} \sigma\varepsilon mbe\sqrt{2gH_u}, e/H<0.6 \\ \sigma_s m_c b_s\sqrt{2g}H^{15}, e/H>0.7 \\ Q_p+10\left(e/H-0.6\right)/\left(Q_w-Q_p\right), 0.6\le e/H\le 0.7 \end{cases} \tag{21}$$

Among them, m is the free outflow flow coefficient of the gate hole, σ and ε are the inundation coefficient and the contraction coefficient of the flat gate hole, b and e are the width of the gate hole and gate opening, g and H_u are the gravitational acceleration and the water depth in front of the gate. m_c is the free overflow flow coefficient of the side contraction weir, σ_s is the inundation coefficient, reflecting the influence of the high downstream water level on the weir top overflow, b_s is the width of the weir after the contraction, and H is the depth of water above the weir. Q_p and Q_w are the overflow calculated according to the gate hole outflow and weir flow formulae, respectively.

2) Visualisation of the projected results. The natural background, flow field dynamics, water conservancy engineering, water conservancy mechanical and electrical equipment visualisation model and the hydrodynamic model are fully integrated with the deduction results data. And the use of simulation engine for real-time dynamic rendering, macro and micro combination of all-round display of the scheduling process and scheduling impact.

3.2.2. Reverse engineering scheduling programme. The design of the garden water resource management model integrating IoT technology is mainly based on the water resource management model constructed in the previous Chapter 2, and three objective functions are added on the basis of the original optimisation objectives, including the minimum amount of deviation between the amount of water distributed and the planned amount of water, the minimum degree of the water level exceeding the safe level in the key sections of the channel, and the minimum number of the average number of gate openings and closures.

The objective functions of the garden water resource management model integrating IoT technology include:

1) Minimum deviation of water distribution from the planned water quantity:

$$f_4 = \sum_{i=1}^{m}\sum_{t=0}^{T}\left|Q_{i,t} - Q_{i,t}^{target}\right| \cdot \Delta t \tag{22}$$

Among them, $Q_{k,t}$, $Q_{k,t}^{taarget}$, respectively, for the i water diversion in the t time diversion flow, the target flow.

2) The water level in the key section of the channel exceeds the safe water level to the minimum extent:

$$f_5 = \sum_{j=1}^{n}\sum_{0}^{T}\left\{\left[Z_{j,t}\left(> Z_{j,safe}\right) - Z_{j,safe}\right]^2\right\} \tag{23}$$

Where $Z_{j,safe}$ is the safe water level of the j nd section, and $Z_{k,t}\left(> Z_{k,ssfe}\right)$ is the value of the water level that exceeds the safety limit at the t th moment of the j th section.

3) The average number of gate openings and closures is minimised:

$$f_3 = \frac{1}{r}\sum_{k=1}^{r} E_k \tag{24}$$

where E_k is the number of times the k nd sluice gate is opened and closed during the scheduling period.

4. Results and analysis of optimal management of water resources in gardens

Landscaping water-saving irrigation is a reference to agricultural water-saving irrigation technology as the premise, and landscaping landscape neither conflict and to meet the plant water requirements. It contains a lot of rich content, in which water conservancy means, garden horticulture means, engineering management means and so on are its main technical measures. In this paper, through the Internet of Things and digital twins through the construction of water resources scheduling and management platform, and then use the water resources management model, to obtain the maximum benefits while improving the actual use of water resources ratio. The following is a study of this paper to test the effectiveness of the methodology of this paper through actual case studies.

4.1. *Study cases*

4.1.1. Overview of the garden area. Park X is located in the city centre area of T, with an area of more than 50,000 m^2, in which a large number of acacia-based trees and a large number of flowering shrubs and grass plants have been planted. According to the type of vegetation, X Park can be divided into A ~ J total of 10 zones, belonging to the region in recent years is relatively new, with water-saving irrigation function of urban greening landscape project.

The park has a pleasant environment and convenient traffic around it. Historically, the soil in the T area has been highly saline and alkaline, so in order to make the plants in the park grow better, practical soil improvement measures were formulated at the early stage of the construction of the park, and a large amount of high-quality planting soil and sandy soil were used for the replacement. With a soil capacity of $1.5g/cm^3$, the park's plant species were designed for large lawns and grasses that require a lot of water.

4.1.2. Irrigation water consumption. The flood season in the area generally begins around mid-June and ends in late August each year, with a normal period of around 70 days, with heavy rainfall generally occurring in mid-July. The cumulative duration of heavy rainfall in a year totals 52 hours, and the volatile evapotranspiration of the water body in the region is 1600mm, with a maximum volatile evapotranspiration of 2835.4mm. The maximum amount of soil freezing occurs in the northern part of the garden area every year, with a depth of up to 1,000mm, and an average value of 600mm for regional freezing.

1) Irrigation water consumption. The total amount of water sprayed by all sprinkler heads in the garden area, including the demand of garden plants in the area, and the unavoidable loss and evaporation volatilisation in the watering process.

The theoretical maximum daily water demand of herbaceous plants and green areas is 5.2 mm/day.

Trees and flowering shrubs theoretical maximum daily water demand of 5 to 8.5 mm / day.

2) Irrigation system. The design irrigation quota is, $m = 0.1rH(\beta_1 - \beta_2)/\eta = 23.05\text{mm}$. Where, r is the dry soil capacity, 1.35 g/cm. H is the depth of the wet layer of the lawn plan, which is 25 cm. β_1 and β_2 are the upper and lower limits of the soil water content, respectively. η is the sprinkler water utilisation factor, which was taken as 0.8 in this study case.

Designed irrigation rotation cycle $T = m / ET = 23.05 / 5.2 \approx 4.43$, the lawn watering frequency was 1 to 2 days in dry and hot months.

4.1.3. Irrigation control methods. X Park through the Internet of Things and digital twin through the construction of water resources scheduling management platform, real-time sensory control of water resources in the garden area. With a rain sensor can be watered according to the size of the rain, while the pump can be turned on remotely; a total of three sets of control procedures can be designed to irrigate four times a day, the amount of water from 10%-200% arbitrary adjustment, according to different rainfall, weather conditions to adjust the length of the irrigation time, the amount of surface water automatically adjusts the size of the irrigation water volume, the convenience of flexible setting time, to prevent the waste of water resources.

4.2. *Results of optimal allocation of water resources*

This paper establishes a water resource management model for garden area based on artificial fish school algorithm based on matlab2021b platform, which is a typical annual optimisation multi-objective model with optimisation step size of years. For the planning level year 2030 and 2035, 50%, 75%, 95% different frequency cases are calculated respectively.

4.2.1. Parameterisation. In terms of the division of water resources in Park X, priority is given to the allocation of surface water, followed by the use of other water resources, and finally the use of groundwater. From the division of users is to ensure the priority of domestic water, then the garden area 10 zones (A ~ J) water, and ecological water. Finally, the order coefficients of different water sources are calculated as 0.4 for surface water ($w1$), 0.3 for groundwater ($w2$) and 0.2 for other water resources ($w3$).

The net benefit coefficient is the difference between the economic benefit coefficient and the price of water. The economic benefit coefficient can be obtained by increasing the water consumption by 10,000 yuan, and the corresponding value can be obtained by taking the reciprocal of the coefficient. Eco-efficiency coefficient is generally combined with experience and local economic development to obtain the corresponding value, the price of water with reference to the T Municipal Development Document, calculated economic efficiency coefficient as shown in Table 1. Among them, the net benefit coefficient is the benefit coefficient - cost coefficient. From the net benefit coefficient of X garden area, D area has the highest net benefit coefficient, which is expected to be 0.05211 and 0.05168 in 2030 and 2035 respectively.

Table 1. The value of economic benefit coefficient

Section	2030 Year			2035 Year		
	Benefit coefficient	Cost coefficient	Net efficiency coefficient	Benefit coefficient	Cost coefficient	Net efficiency coefficient
A region	0.04676	0.01370	0.03306	0.04233	0.01350	0.02883
B region	0.03277	0.01156	0.02121	0.02333	0.01140	0.01193
C region	0.02983	0.01905	0.01078	0.02488	0.01858	0.0063
D region	0.07009	0.01798	0.05211	0.06953	0.01785	0.05168
E region	0.06917	0.01878	0.05039	0.06135	0.01863	0.04272
F region	0.04777	0.00720	0.04057	0.04273	0.00702	0.03571
G region	0.01495	0.00844	0.00651	0.01420	0.00820	0.00600
H region	0.05852	0.01671	0.04181	0.05307	0.01648	0.03659
I region	0.01377	0.01270	0.00107	0.01185	0.00256	0.00929
J region	0.03962	0.01765	0.02197	0.03201	0.01748	0.01453

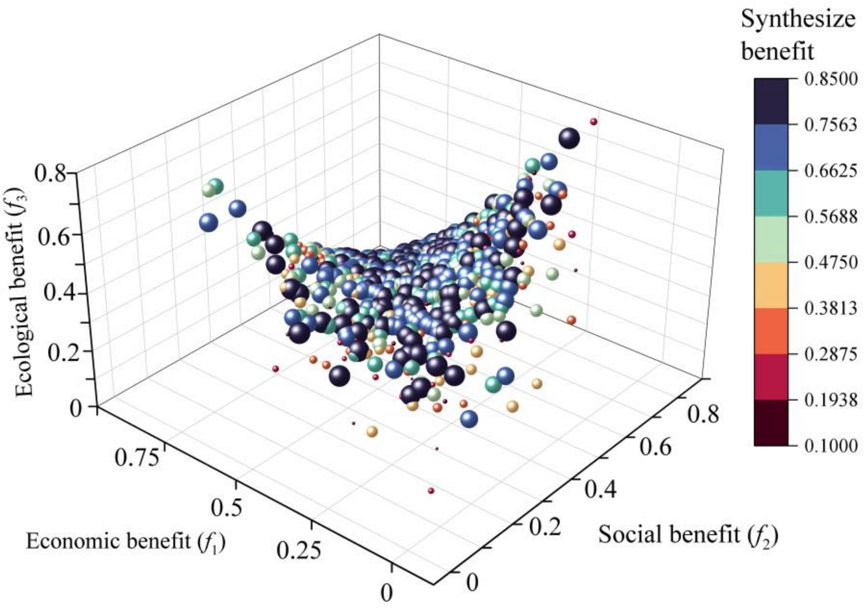
The parameter inputs of the multi-objective water resource optimisation and management model are shown in Table 2, where $w1$, $w2$ and $w3$ are surface water, groundwater and other water resources, respectively. Based on the experience and trial calculations, the population size of the artificial fish population algorithm was set to 3000, the number of grids for each annotation was set to 10, the expansion rate α was set to 0.2, the inertia weight ϖ was taken as 0.6, and the number of iterations was set to 2000. The frequency was set to 50%, 75%, and 95% in three different scenarios.

Table 2. Parameter input of multi-objective water resources optimal allocation model

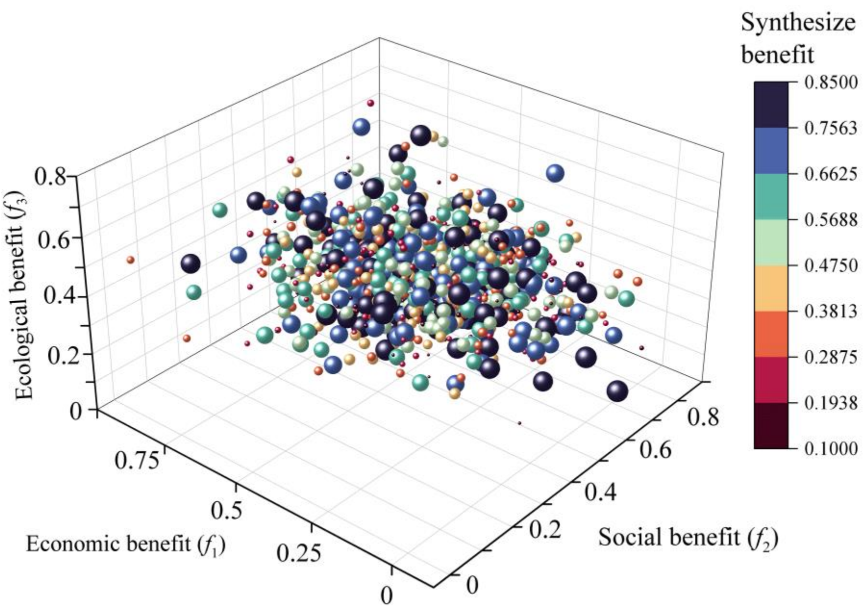
Year	2030 Year			2035 Year		
Frequency	50%	75%	95%	50%	75%	95%
A region	427.46	424.64	433.49	475.04	487.09	462.17
B region	1143.11	1136.36	1132.26	1158.20	1153.31	1165.54
C region	825.87	841.92	825.46	852.72	858.60	892.44
D region	82.94	94.41	86.06	134.70	140.33	141.58
E region	74.54	69.23	61.83	80.00	117.60	124.77
F region	1170.95	1173.79	1173.42	1214.28	1223.09	1198.11
G region	323.99	327.91	339.22	370.55	345.54	346.29
H region	435.50	432.16	436.39	483.41	478.60	473.07
I region	61.33	75.99	64.17	128.12	115.47	119.09
J region	2203.13	2198.19	2198.90	2230.16	2211.16	2236.30
$w1$	519.44	526.86	531.16	550.55	556.46	548.86
$w2$	26.95	24.25	41.70	50.38	67.68	76.18
$w3$	427.46	424.64	433.49	475.04	487.09	462.17
Population size			3000			
Grid number			10			
Expansion rate α			0.2			
Inertia weight ω			0.6			
Number of iterations			2000			

As this paper constructs a matrix model with multi-objective and multi-constraint complex non-vectors, finally a set of pareto optimal solution set is obtained after the model calculation. The objective functions are constrained by each other, and the optimal solution of one objective function may have low adaptability to other objective functions or fail to meet its basic requirements, and the tendency of the solutions in the pareto-optimal solution set is also different from each other. Therefore, it is necessary to select the optimal solution from the set of pareto optimal solutions that meets the regional realities and the needs of water resources planning as the optimal solution. In selecting the optimal solution, the principle of rational allocation and coordinated development is followed, and the rational allocation of water resources among different water users and the pursuit of coordinated economic, social and ecological development are considered.

4.2.2. Analysis of configuration results. The artificial fish swarm algorithm is used to solve the water resource management model for the garden area, and the Pareto solution set for each planning year under different frequencies is shown in Fig. 3, and the Pareto solution set is brought into the net benefit model for calculation, and the comprehensive benefits of water resources for each planning year are obtained as shown in Table 3. As can be seen, the Pareto optimal solution for maximising economic benefits is (0.467, 0.289, 0.257). In the planning year 2030, the integrated benefits at different frequencies are 0.781, 0.737 and 0.816. In the planning year 2035, the integrated benefits at 50%, 75%, and 90% frequencies are 0.689, 0.772, and 0.833, respectively, and the integrated benefits are higher than 0.7, which tests the validity of the model of water resources management in the garden area.



(a) Planning year 2030



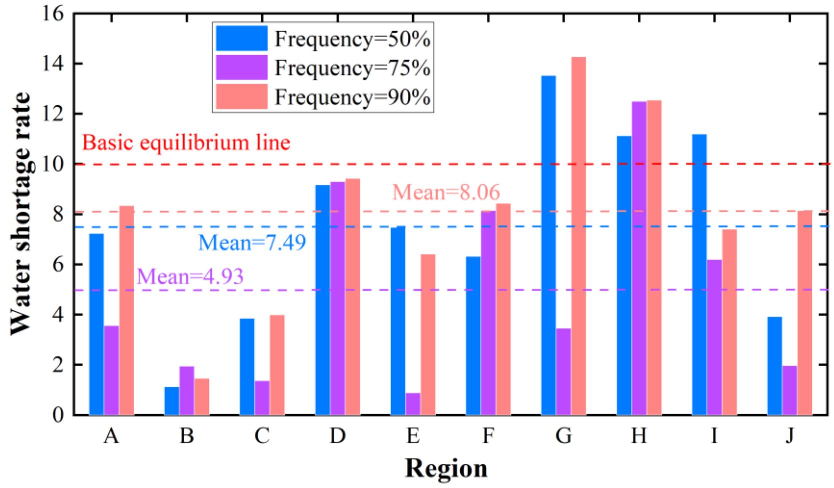
(b) Planning year 2035

Fig. 3. Pareto solution sets for each planning year with different frequency

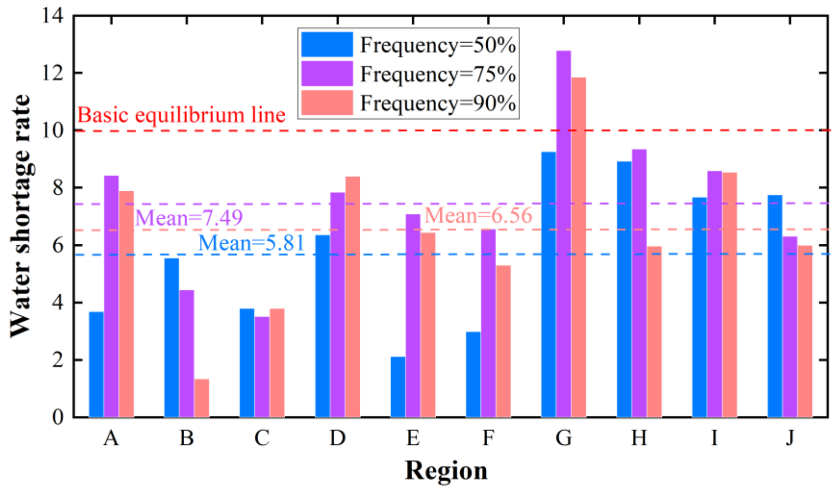
Table 3. Comprehensive benefits of water resources in each planning year

Frequency		Economic benefit (f1)	Social benefit (f2)	Ecological benefit (f3)	Synthesize benefit
2030	50%	(0.467, 0.289, 0.257)	(0.451, 0.295, 0.223)	(0.498, 0.293, 0.217)	0.781
	75%		(0.221, 0.368, 0.424)	(0.232, 0.365, 0.402)	0.737
	90%		(0.452, 0.247, 0.267)	(0.487, 0.258, 0.268)	0.816
2035	50%		(0.410, 0.284, 0.286)	(0.431, 0.287, 0.289)	0.689
	75%		(0.351, 0.228, 0.421)	(0.368, 0.224, 0.401)	0.772
	90%		(0.183, 0.551, 0.276)	(0.215, 0.526, 0.275)	0.833

4.2.3. Analysis of water scarcity rates. The calculation of water shortage rates at different frequencies for the planning year of X garden area based on the results of the optimal allocation is shown in Figure 4. Among them, Fig. 4(a) shows the statistical results of water shortage rate in planning year 2030. It can be seen that at 50% frequency in 2030, the supply and demand of each region of X Garden Forest is basically balanced, and the water shortage rates of G, H and I are 14%, 11% and 11% respectively, which is a mild water shortage. The rest of the regions have a shortage rate of less than 10%, which is a basically balanced area.At 75% frequency in 2030, except for Zone H, which has a shortage rate of 13%, which is a mild shortage, all other zones have a shortage rate of less than 10%, which is in a basically balanced area.At 95% frequency in 2030, Zone G and H have a shortage rate of 14% and 13%, which is a mild shortage, and the rest of the zones have a shortage rate of less than 10%, which is in a basically balanced area. Figure 4(b) shows the results of the water shortage rate statistics for the planning year 2035, and it is also found that most of the areas in X-Park Forest can reach a basic balance between supply and demand.



(a) Planning year 2030



(b) Planning year 2035

Fig. 4. X Water shortage rate of different frequency in garden area planning years

The fact that the total water supply of the optimal allocation scheme is not equal to the available water supply characterises the optimal multi-objective management model of water resources. Although it is possible to maximise the economic benefits of allocating the entire available water supply to the sub-zones, the larger the supply, the more pollutants will be generated by the water sectors. However, the larger the water supply, the more pollutants are generated by each water sector, which is more likely to result in a large difference in the water shortage rate of each sub-district and uneven water distribution. From the perspective of sustainable development, the allocation scheme with optimal comprehensive benefits weighs each objective function and achieves coordinated economic, ecological and social development.

4.2.4. Configuration target analysis. Considering the economic objectives (f_1), social objectives (f_2), and ecological objectives (f_3) of the X Garden, the obtained objective function values of the optimal allocation of water resources in the X Garden area were compared with those of the conventional scheme, and the specific results are shown in Table 4. Compared with the conventional allocation scheme, the optimal scheme can significantly improve the economic benefits, and the optimal scheme increases the economic benefits by 1987, 1105, and 1037 compared with the conventional scheme at 50%, 75%, and 95% frequencies in 2030, and by 1199, 1338, and 1462 compared with the conventional scheme in 2035.At the same time, the optimal scheme can improve the social benefits, reduce the sub-districts' of the water shortage rate gap and promote water equity. The increase in the values of the objective functions in 2035 compared to 2030 is due to the increase in water demand by water users and the acceleration of urbanisation as a result of economic and social development.

Table 4. Objective function value of conventional scheme and optimization scheme

Level year		2030			2035		
Frequency		50%	75%	90%	50%	75%	90%
Economic benefit (f1)	Conventional scheme	4080	4833	4729	9836	9245	9137
	Optimization scheme	6067	5938	5766	11035	10583	10599
	Difference	1987	1105	1037	1199	1338	1462
Social benefit (f2)	Conventional scheme	4.3	3.2	3.7	3.5	2.8	5.1
	Optimization scheme	14.1	12.6	11.3	10.5	14.2	13.5
	Difference	9.8	9.4	7.6	7.0	11.4	8.4
Ecological benefit (f3)	Conventional scheme	119244	118342	115824	137806	135024	134546
	Optimization scheme	128376	127805	127534	150530	153321	152835
	Difference	9132	9463	11710	12724	18297	18289

With the increase of frequency in each planning year, the economic benefit generated by water supply in X garden area decreases, and at the same time, pollutant emission decreases, and ecological benefit increases. The Gini coefficient of the water shortage rate in each sub-area decreases, the social benefits increase, and the configuration results are consistent with multi-objective optimisation in which each objective competes with each other, mutual constraints are imposed, and the improvement of one objective is at the expense of several others. The optimal management scheme ensures high water supply efficiency while reducing pollutant emissions and improving water use efficiency.

5. Conclusion

The study takes into account the actual operation of the garden area, and establishes a water resources management model based on the balance of water resources supply and demand, with the maximisation of economic, social and ecological benefits as the optimisation goal. Based on the Internet of Things and digital twin technology, the water resources scheduling management platform of the garden area is constructed, which realises the fine management of water resources and intelligent decision-making of scheduling. Combined with the actual situation of X garden area, each parameter of the model is determined, and the artificial fish swarm algorithm is used to solve the model, which results in the Pareto solution set of the water resource allocation scheme under different frequencies in each planning year. Configuration results show that X garden forest area has formed a water supply structure centred on surface water and groundwater sources, with a variety of water sources jointly supplying water, which improves the emergency guarantee capacity of water resources, except for a small number of areas where the water shortage rate is greater than 10%, which belongs to a mild water shortage after optimal allocation. Most of the regions have a water shortage rate of less than 10%, in a basic supply balance. Comparing the optimised scheme with the conventional scheme, it is found that the water shortage rate of the optimised scheme is always smaller than that of the conventional allocation scheme under each frequency. At the same time, the optimised scenario can significantly improve the economic, social and ecological benefits and provide a basis for water resources management.

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