Research on Water Resources Saving Based on Chaotic Particle Swarm Optimization

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Abstract

To improve the saving level of water resources, and the optimal allocation model of water resources is constructed, and the chaotic particle swarm optimization is established to solve the optimal allocation model. Firstly, the relevant researches are summarized, and the main contributions of this research are given. Secondly, optimal allocation conception of water resources is discussed, and then the corresponding optimal allocation model is established. Thirdly, the chaotic particle swarm optimization model is established, and the analysis procedure of the proposed algorithm is designed. Finally, optimal allocation analysis of water resources is carried out, and optimal allocation plans of water resources are confirmed, results show that the proposed optimal model and its solving algorithm can effectively obtain the best effect.

Keywords: Water resources saving, chaotic particle swarm algorithm, optimal allocation of water resources.

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1 Introduction

Improving the optimal allocation of water resources and the ability to prevent flood and drought disasters, and improving level of intensive and safe of water resources are final object of building a socialist modern country in an all-round way. Water is an important resource integrating resource elements, ecological elements and carrier elements. The intensive and safe utilization of water resources conclude three meanings: first, effectively protect the quality and quantity of water resources, ensure long time application of water resources. The second is to apply water resources in the water field, and use means of economical use, and enhance application efficiency of water resources; The third is to ensure security of water resources.

Water resources have become a main factor limiting social and economic advancement in northern China, and the amount of water resources in northern cities is very scarce. For a long time, due to the unreasonable use of surface water and groundwater, there have been similar problems: low using productiveness of water resources, unbalanced development of water resources, large exploitation of groundwater, serious waste of water and so on, which have greatly disturbed people's production quality and quality of life. In conclusion, the optimal allocation of water resources in cities has been an important problem to be solved urgently, and improve using level of local water resources by scientifically adjusting the regional water supply and consumption structure and reasonably allocating the regional limited water resources, to offer basis for the sustainable development of urban social economy. However, when facing the complexity and uncertainty of water resources system, the traditional allocation methods often only make empirical estimation or ignore it, resulting in the deviation of allocation results. Hence, it is crucial to study how to realize the sustainable development and utilization of water resources, and carry out the research on the saving of urban water resources.

Focusing on basic characteristics of water resources, allocation of water resources is to analyze relationship between long term utilization of water resources and development of urban, along with the contents, objectives and methods of optimal allocation. A water resources allocation model based on water rights distribution was constructed, which integrates the game among market economy, government macro-control and water resources attributes into the model. A robust, scientific and cost-effective method should be established.

A widely used method of constructing optimal allocation model is to quantitatively analyze the planned annual allocation problem by analyzing the objectives represented by water supply and demand. The applicability of objective function of the configuration model and the accuracy of the constraints determine the rationality of the calculation results. At the same time, water quality constraints are added to the model constraints. The development of water resources is set as three quantitative standards: sustainable development, environmental carrying and economic achievements. In the way of water supply, this paper puts forward the joint dispatching and configuration scheme of multiple water sources, comprehensively considers multiple surface and underground water sources, obtains that the minimum cost of multi-source comprehensive water supply is the objective function, obtains the minimum objective function of water shortage based on water balance analysis, and obtains the maximum objective function of project achievement based on economic theory [1].

As information technology developed, the method of solving the model is constantly updated based on characteristics of optimal allocation model and the complexity of different objective functions. Based on the traditional genetic algorithm, the penalty function is added to fuzzy range to solve the linear and nonlinear water resources planning models. By analyzing the impact of water distribution system on water consumption, user behaviour and national expected objectives, this paper studies the effectiveness of Tunisia's water resources allocation system. Aiming at the high-dimensional multi-objective model, an novel particle swarm algorithm is proposed by combing with fuzzy theory.

With the improvement of technical methods and the complex changes of research objects, new evaluation indicators are continuously integrated into the index system, such as resource management, precipitation, water price transaction, resource welfare index, development and utilization mode, import dependence, etc., forming a relatively rich correlation index results. For the evaluation of using water resources efficiency, we usually start with the constructed index system and use qualitative or quantitative methods to calculate the evaluation results. At present, the main shortcomings are as follows: for the research on the evaluation of water resources using efficiency by constructing the index system, there are some difficulties in setting the index standard, and there are many artificial and objective factors. Moreover, the application of the evaluation results is poor, and there is a lack of operation to integrate the evaluation results into the optimal allocation model. The evaluation is generally carried out after the optimization process, which does not give full play to the utility of evaluation analysis [2].

In the solution of optimal allocation model, linear programming methods were mostly used in the early years, such as mixed integer, uncertain random fuzzy and other improved programming methods. With the increasing complexity of the model, the traditional mathematical model has been unable to adapt. The methods of solving the objective function have changed from planning methods and fuzzy methods to intelligent search algorithms, such as particle swarm optimization algorithm, Bayesian network, random forest, non dominated sorting genetic algorithm and so on. Particle swarm optimization algorithm absorbs the information sharing strategy and learning strategy of bird swarm, so that the algorithm can effectively reduce the running time and improve the speed and accuracy of solving optimization problems. Because of its simple algorithm principle, less program and fast convergence speed, it has been widely used in many fields such as function combination optimization. However, with the complexity of application problems, people find that it is easy to fall into local optimization and dimension disaster. Particle swarm optimization must initialize the population particles (random solution) before cyclic iteration, and then update the population particles through a limited number of iterations. The output at the end of the iteration is the optimal solution found by this particle swarm optimization. Because PSO is a probabilistic algorithm, the update of particle velocity and position has great randomness, which can not guarantee that it can search the optimal solution within the number of iterations. In the later stage of iteration, the particles are easy to "gather" and fall into the local optimum, which makes it difficult for the subsequent iterative particles to jump out of the local optimum. The weight coefficient of particle swarm optimization is an important factor affecting the algorithm results in searching the optimal matching scheme. The weight coefficient of conventional particle swarm optimization algorithm is a fixed value. In order to avoid particle swarm optimization falling into local optimization, chaos theory is used to dynamically adjust the weight factor. This research aims to carry out optimal allocation of water resources based on the chaotic particle swarm optimization [3, 4]. The current analysis method has the disadvantages of low efficiency and precision, and the proposed particle swarm algorithm can effectively improve the accuracy and efficiency of optimal analysis.

2 Basic Theory of Optimal Allocation of Water Resources

Water resources allocation refers to the use of engineering or non engineering measures to scientifically plan and allocate limited water resources within a designated watershed or a certain region, so as to ensure the coordinated development of economy, society and ecology. The purpose of optimal allocation of water resources is to improve the distribution efficiency of water resources and coordinate the competition between various water users. The second is to improve the water efficiency of departments, promote efficient water use in the industry and all departments, and promote the formation of water-saving mechanism. There are differences in the congenital conditions of water resources in different regions or watersheds. For areas with sufficient water resources, the optimal allocation is reflected in the optimal adjustment of regional industrial structure and the rational layout of productivity. For areas lacking water resources, the optimal allocation emphasizes the coupling between the scientific allocation of water demand departments and the optimization and adjustment of regional industrial structure, so as to maximize achievements and promote the overall coordinated development of the region. The optimal allocation of water resources belongs to the overall strategic planning [5].

Principle of macro-control: Water resources are basic natural resources. According to the provisions of China's water law, the ownership of water resources belongs to the state and collective. On this premise, water resources belong to public resources for all walks of life. The economic attribute of water resources makes it a commodity regulated by the market. Its natural and economic attributes determine that the optimal allocation of water resources cannot be managed unilaterally by the government or the market, but should be controlled by the government's macro-control under the market allocation environment. The optimal allocation of water resources needs to abide by the principle of macro-control.

Total amount control principle: In the areas where water resources are scarce, the core goal of optimal allocation is to achieve the balance of supply and demand, and the controllability of the total amount is an important means to achieve the balance of supply and demand. In order to strengthen the scientific management of water resources and promote water conservation in all walks of life, the state has established a standard index system for planned water use and water conservation, and implemented water quota management. For the part exceeding the quota, strict punishment measures shall be taken to transform the external water competition into the internal excavation of water-saving space. The total amount control not only includes the control of water quantity, but also includes the emission limit of pollutants, so as to further improve the problem of water quality water shortage [6].

Principle of effectiveness: In the economic environment, water contributes to human material life and spiritual life. In the social environment, water is important for river management and ecological balance. The operation purpose of water resources supply under the market economy is to maximize the return on investment, but the simple pursuit of maximizing economic achievements can cause the ecosystem imbalance. The optimal allocation is to pursue comprehensive optimization of social, economic and ecological achievements of water resources use under condition of coordinated advancement of all links. The principle of effectiveness is not simply one side effectiveness, but the comprehensive effectiveness of pursuing social, economic and ecological achievements.

Principle of fairness: Everyone has the right to use water resources equally, especially to ensure the basic needs of poor areas. At the same time, as a basic resource, water resources are widely used and indispensable in agricultural irrigation and industrial production. Under this principle, optimal allocation needs to coordinate the water contradictions among various water users at all levels of society and meet the interests of all parties. Fairness not only emphasizes the coordination among production, life and ecology, but also emphasizes the implementation of fair distribution among different regions. This fairness is not an absolute average, but has the same attention to the water demand of each region. Not only equity should be reflected in resource planning, but also high efficiency and relative equity should be fully reflected in water conservancy project implementation, management system reform, water price mechanism adjustment and investment policy [7].

Principle of sustainability: The theory of sustainable development originated from the phenomenon of environmental damage, and the sustainability of natural resources has always been an important topic. Currently, there is a steady demand for water resources. However, overuse of water resources may lead to imbalance of ecological environment, and the deterioration of environment will react on the fields of human production and life. Therefore, in the process of optimal allocation, we need to consider the short-term and long-term sustainability of water resources. The advancement of contemporary people cannot be based on sacrificing the interests of future generations.

Principle of priority: Under limited resources, when facing different water needs, it can be configured according to the principle of priority. Survival is the primary theme of mankind. In years of serious water shortage, living water required for survival should be ranked among the most priority water needs. In addition, it is also clearly stated in the water intake system that priority should be given to ensuring residents' domestic water. In order to make up for the damage to nature, regional ecological water use should also be given priority; For the area where water flows, priority should be given to the right to obtain water resources in the basin, so as to reduce the consumption of water intake funds. In the open source and throttling of water resources safeguard measures, throttling should be given priority, which is in line with the construction of water-saving cities [8].

Principle of reasonable water price: Economic attribute of water resources adds economic regulation means to the optimal allocation. In a very long period of time, water prices are low, and water resources appear more as a "welfare". This low price phenomenon does bring some achievements to people, but it also hides great harm early, and forms bad water habits and unhealthy water awareness, resulting in uncontrolled waste. Water price consists of engineering water price, environmental water price and resource water price. Factors such as different regions, water source types and quantity differences will affect resource water price.

3 Optimal Allocation Model of Water Resources

According to above principles, the optimal allocation of water resources uses some technical methods in some specific areas to scientifically and reasonably allocate the limited water resources to various water departments. Therefore, this study constructs a comprehensive evaluation function aiming at social, economic and ecological achievements, which is expressed by [9]:

$$W = opt\{g_e(x), g_s(x), g_{ec}(x)\} \tag{1}$$

where x illustrates decision variable, $g_e(x)$ denotes economic achievements, $g_s(x)$ demotes social achievements, $g_{ec}(x)$ denotes ecological achievements.

Economic achievement objectives: taking the maximization of direct economic achievements of water users in different level years as economic achievement goal, the expression is [10]

$$\max\ g_e(x) = \max\left[\sum_{i=1}^{I(m)}\sum_{j=1}^{J(m)}\sum_{m=1}^{M} W_{ij}^m (R_{ij}^m - F_{ij}^m)\lambda_i^m \rho_j^m\right] \tag{2}$$

where i denotes the category of regional water supply source, j illustrates the category of regional water users. W_{ij}^m illustrates the water supply, R_{ij}^m illustrates the achievement coefficient, F_{ij}^m illustrates the cost coefficient, λ_i^m denotes water supply ratio, ρ_j^m denotes water equity ratio.

Social achievement objectives. The objective of social achievements is to minimize the regional comprehensive water shortage ratio, and expression is

$$\max\ g_s(x) = -\min\left\{\sum_{j=1}^{J(m)}\sum_{m=1}^{M}\left[\frac{E_j^k - \sum_{i=1}^{I(m)} W_{ij}^m}{E_j^k}\right]\right\} \tag{3}$$

where E_j^k illustrates the water demand of water users in the m sub region.

Ecological achievement objectives. Taking the minimization of the total amount of important pollution factors (chemical oxygen demand, COD) discharged by each water user in the corresponding planning level year as the ecological achievement goal, the expression is

$$\max\ g_{ec}(x) = -\min\left(\sum_{i=1}^{I(m)}\sum_{j=1}^{J(m)}\sum_{m=1}^{M}\frac{P_j^m \eta_j^m W_{ij}^m}{100}\right) \tag{4}$$

where P_j^m illustrates the amount of important pollution factors contained in unit volume wastewater, η_j^m denotes sewage discharge ratio.

In the process of optimal allocation of water resources, due to complexity and uncertainty of the water resources system itself and the multi-objective characteristics of allocation model, the general linear constraints are difficult to meet the allocation requirements, resulting in the unsatisfactory allocation results. Therefore, on the basis of following the allocation principle, the boundary conditions of water supply capacity, water demand capacity, environmental carrying capacity and non negative variables are considered at the same time. The boundary conditions are listed as.

Boundary condition 1: The total amount of water supply shall be less than its maximum available water supply, and the expression is [11]:

$$\sum_{j=1}^{J(m)} W_{ij}^m \le U_{i\max}^m \tag{5}$$

where $U_{i\max}^m$ illustrates the maximum available water supply.

Boundary condition 2: amount of water obtained by each water user from the water source i shall be combined with their own water demand capacity, which shall not be less than the minimum constraint or exceed the rated constraint. The expression is:

$$\omega_j^{m-1} W_{ij}^m \le \sum_{j=1}^{J(m)} W_{ij}^m \le \omega_j^{m+1} W_{ij}^m \tag{6}$$

Boundary condition 3: The content of important pollution factors contained in unit volume wastewater discharged by each water user shall be within the national allowable discharge index; The total amount of important pollution factors discharged shall not exceed the maximum allowable emission of the area, and the expression is:

$$\min\left(\sum_{i=1}^{I(m)}\sum_{j=1}^{J(m)}\sum_{m=1}^{M}\frac{P_j^m\eta_j^m W_{ij}^m}{100}\right)\leq T_{\max}^m \tag{7}$$

$$P_j^m \leq C_j^0 \tag{8}$$

where $T_{\max}^m$ illustrates the maximum allowable total amount of important pollutants discharged in the m sub region, C_j^0 illustrates the COD mass concentration of important pollutants discharged in standard specifies.

Boundary condition 4: The water supply shall meet non negative constraints, and the expression is:

$$W_{ij}^m \geq 0, \quad i,j = 1,2,3,\dots \tag{9}$$

4 Solution Method for Optimization Allocation Model of Water Resources

The individual of particle swarm optimization algorithm gradually approaches the optimal target by comparing the optimal position passed by itself with the optimal position of other individuals in the population, and constantly adjusting the individual speed. Each individual is called a "particle". Each particle is a solution vector in N-dimensional space. $x_i = (x_1, x_2, \dots, x_n)$ is used to denote location, and the fitness degree of all particles is computed in particle swarm, and the local optimization position P_b and global optimization G_b are obtained. On the basis of these two optimal values, the global optimal value is continuously approached through the iterative update of velocity v.

The location updating formula is listed as follows [12]:

$$v_i(t+1) = w_1\cdot v_i(t) + D_1\cdot R_1\cdot(P_{bi} - x_i(t)) + D_2\cdot R_2\cdot(G_{bi} - x_i(t)) \tag{10}$$

$$x_i(t+1) = x_i(t) + v_i(t) \tag{11}$$

The fitness is computed as

$$f(x_i) = \sum_{k=1}^{m} S(x_k, k) \tag{12}$$

where D_1 and D_2 are constants, t illustrates the current iteration times, w_1 is the weight, R_1 and R_2 illustrates random number, which range from 0 to 1.

Two inertia weight adjustment mechanisms, dynamic P chaotic mapping and nonlinear equation, are used to dynamically adjust the weight. Compared with the traditional logistic mapping, which uses a unified method to modify all particles, dynamic P chaotic mapping and nonlinear equation can better dynamically adjust the particles in different states.

P chaotic mapping formula is [13]

$$p(t+1) = \frac{p(t)}{\lambda}, \quad 0 < p(t) < \lambda \tag{13}$$

$$p(t+1) = \frac{1-p(t)}{1-\lambda}, \quad \lambda < p(t) < 1 \tag{14}$$

where p is the result of chaotic mapping, λ is the chaotic factor.

The weight is calculated by:

$$\xi = \xi_{\max} - (\xi_{\max} - \xi_{\min}) \left(\frac{T}{T_{\max}} \right) \tag{15}$$

$$w_1 = \xi - (1 - \xi) \cdot p \tag{16}$$

where T denotes current cycle times, $T_{\max}$ denotes maximum iteration times. ξ is weight adjustment factor.

Dynamic nonlinear equation weight adjustment formula is listed as follows [14]:

$$\nu = \nu_{\max} - (\nu_{\max} - \nu_{\min}) \left(\frac{T}{T_{\max}} \right) \tag{17}$$

$$w_1 = w_{1\max} - (w_{1\max} - w_{1\min}) \left(\frac{T}{T_{\max}} \right)^{v} \tag{18}$$

where ν is adjustment coefficient of weight.

The steps of dynamical chaotic particle swarm algorithm are listed as follows:

Step 1: Set initial value of D_1 and D_2, the size of particle swarm and the maximum iteration times $T_{\max}$. Let current iteration time $T = 0$. Set the P chaotic initial parameter p, maximum and minimum dynamical nonlinear inertia weight adjustment factors $\nu_{\max}$ and $\nu_{\min}$.
Step 2: Set initial velocity v_0 and initial location x_0 of every particle randomly, calculate initial fitness $f(x_0)$. Record the individual optimal value P_{b0} and global optimal value G_{b0}.
Step 3: For every particle, compare fitness degree $f(x_i)$ and individual optimization value P_{bi}, if $f(x_i) > P_{bi}$, replace P_{bi} using $f(x_i)$.
Step 4: For every particle, compare fitness degree $f(x_i)$ and current global optimization value G_{bi}, if $f(x_i) > G_{bi}$, replace G_{bi} using $f(x_i)$.
Step 5: If $f(x_i) < F_{mean}$, update the weight w_1 based on Equations (14) and (15). If $f(x_i) > F_{mean}$, update the weight w_1 based on Equations (16) and (17), and update the velocity and location of particle.
Step 6: If the current number of iterations time T is greater than or equal to $T_{\max}$, the current optimal particle is output; otherwise, execute step 3.

5 Case Study

To check effectiveness of proposed optimal model, a city is selected to carry out optimal allocation simulation. The optimal allocation of water resources in the city takes each administrative sub district as the basic unit. In order to comply with the current administrative division and ensure the effective use of historical data, it is studied according to the current administrative division of the city, taking the central urban area as a sub district and the other districts

Table 1 Water resources and water efficiency

Number of Sub Region	Surface Water Resources/ Million Cubic Metres	Groundwater Resources/ Million m^3	Water Production Coefficient	Water Consumption Per Ten Thousand Yuan GDP/m^3/Ten Thousand Yuan
1	85453	10944	0.55	9.65
2	43954	6954	0.54	10.34
3	33952	4236	0.55	11.20
4	59854	15849	0.52	15.63
5	22948	5986	0.54	16.92

Table 2 Optimal allocation plan of water resources in this city

Number of Sub Region	Water Category	Optimal Plan of Social Objective/ Billion m^3	Optimal Plan of Economic Achievements/ Billion m^3	Optimal Plan of Ecological Achievement/ Billion m^3	Optimal Plan of Comprehensive Achievements/ Billion m^3
1	Agricultural water	0.695	0.653	0.713	0.686
	Industrial water	1.430	1.685	1.550	1.694
	Thermal power water	2.130	2.014	2.254	2.186
	Urban public water	2.665	2.645	2.465	2.542
	Residential water	2.320	2.437	2.394	2.405
	Ecological environment water	0.394	0.376	0.382	0.358
2	Agricultural water	0.334	0.325	0.3043	0.311
	Industrial water	0.329	0..313	0.298	0.313
	Thermal power water	0.022	0.023	0.020	0.021
	Urban public water	0.355	0.342	0.326	0.336
	Residential water	0.556	0.534	0.562	0.548
	Ecological environment water	0.667	0.626	0.685	0.661
3	Agricultural water	0.594	0.586	0.579	0.591
	Industrial water	0.885	0.896	0.915	0.906
	Thermal power water	0.012	0.011	0.014	0.015
	Urban public water	1.232	1.226	1.325	1.275
	Residential water	1.532	1.623	1.734	1.684
	Ecological environment water	0.995	0.986	0.992	0.988
4	Agricultural water	0.568	0.559	0.534	0.548
	Industrial water	0.329	0..313	0.298	0.313
	Thermal power water	0.081	0.073	0.069	0.078
	Urban public water	0.355	0.342	0.326	0.336
	Residential water	2.116	2.265	2.237	2.316
	Ecological environment water	3.213	3.143	3.235	3.326
5	Agricultural water	0.495	0.489	0.477	0.485
	Industrial water	0.558	0.545	0.586	0.573
	Thermal power water	0.081	0.073	0.069	0.078
	Urban public water	0.221	0.249	0.258	0.253
	Residential water	1.345	1.545	1.456	1.447
	Ecological environment water	2.445	2.531	2.454	2.502

as a sub district, a total of 5 sub districts. For the sub areas that have changed in the historical stage, the water consumption data shall be divided according to the proportion of their administrative area, so that the historical data can meet the current administrative division under the condition of total amount, and the processed data can be used for the subsequent optimal allocation model. The urbanization rate is 67.27%. The central urban area of the city has the largest population and density.

Water resources conditions in this city are listed in Table 1.

The statistics of water resources in the city generally include agricultural water, general industrial water, thermal power water, urban public water, residential water and ecological environment water. The optimal allocation in this city is confirmed by combining with chaotic particle swarm algorithm, and results are listed in Table 2.

As seen from Table 2, total water supply of optimal allocation and water shortage ratio of every sub region can be obtained based on proposed model. Comparing comprehensive achievement optimal allocation scheme with each single objective optimal scheme, the comprehensive achievement optimal scheme balances the three objective functions. When the total demand is greater than the total available, each sub district undertakes a certain degree of water shortage, which differentiates the difficulty of water saving. Compared with the ecological optimal scheme, the optimal allocation scheme of comprehensive achievements ensures the general needs of economic development and will not cause excessive constraints on the economy due to environmental protection.

6 Conclusions

The chaotic theory is combined with particle swarm algorithm to establish chaotic particle swarm algorithm, the proposed chaotic particle swarm algorithm is used to deal with optimal model. A city is selected to be research objective to carry out optimal allocation of water resources based on chaotic particle swarm algorithm, and optimal plans of social objective, economic achievement, ecological achievement and comprehensive achievement for different sub regions in this city are obtained, the optimal model can effectively improve the analysis precision and efficiency, the optimal is an novel method of optimizing the water resources and analysis results can provide basis for making management measures of water resources saving.

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Biography

Jiang Yongcong, lecturer of Henan Forestry Vocational College, received his master's degree of Computer Technology from Henan University of Science and Technology. He was awarded the title of Young Backbone Teacher of Henan Higher Vocational Colleges, Excellent Tutor of Henan Province and host of Excellent Online Open Course "Network Security" in Henan Province. He has won the second prize of Informatization Teaching Competition in National Vocational Colleges, the Gold Medal of the First National Forestry Innovation and Entrepreneurship Competition and the first prize of Teaching Achievement Award of China Communication Industry Association.