Journal of Theoretical and Applied Information Technology
31st March 2013. Vol. 49 No.3

ISSN: **1992-8645** www.jatit.org E-ISSN: **1817-3195**

COMPLEX ADAPTIVE SYSTEM-BASED OPTIMAL ALLOCATION OF REGION WATER RESOURCES

[1]FENG KEPENG, [2]TIAN JUNCANG
[1,2] College of Civil and Hydraulic Engineering, Ningxia University, Yinchuan 750021, China
[1,2] Ningxia Research Center of Technology on Water-saving Irrigation and Water Resources Regulation, Yinchuan 750021, China
[1,2] Engineering Research Center for Efficient Utilization of Water Resources in Modern Agriculture in Arid Regions, Yinchuan 750021, China
E-mail: [1]fengkp@gmail.com , [2]slxtjc@163.com

ABSTRACT

Because of disadvantages to traditional theory and methods on optimal allocation of water resources , This paper views the system of regional water resources as a Complex Adaptive System composed of many independent agents , and studies its complexity with the complex adaptive system (CAS) theory. Based on CAS, we propose a new framework for the allocation of region al water resources. Then ,the simulations were performed in Ningxia region to verify the effectiveness of the theoretical framework.

Keywords: *Complex Adaptive System, Optimal Allocation, Water Resources, complexity, Agent Modeling*

1. INTRODUCTION

Accompanied China's rapid social and economic development, water shortages are exacerbated further highlight the competition for water, also facing severe challenges of floods, pollution, unreasonable allocation of water resources and water environment deterioration. In the development process, how to not only to maintain a harmonious relationship between man and water, but also take into account the social justice and economic efficiency of water resources between rich and poor regions, is an important issue to solve. Especially the rational allocation problem of water resources in the inter-regional, inter-sectoral, is already a focus of many of the contradictions to the dryland in the development process.

Allocation of water resources is a human process of re-allocation of water resources and the environment, is also an important measure of the coordination of water and human relations. The water system is a “natural – artificial” combination of binary systems with physical, chemical, biological, and many other attributes. It is not only interdependent but mutual restraint in macro-economic systems, ecosystems, resources, and environment. For such a complex system, the optimal allocation of water resources is an extremely complex process.

Since the 1990s, scholars based on the theory of systems engineering carried out many useful discussions and practice on the optimal allocation of water resources and management theories and methods. Which the representative: Water system hierarchical control theory, the theory of water resources ecological and economic system, water system operation scheduling management decision support system, the basin complex systems theory, water resources complex adaptive system configuration model, for the whole property features water resources allocation concept.

Nonlinear science and complexity, since the 1980s, has been a very good development, especially of complex adaptive systems theory in 1994 proposed is a new breakthrough. It is a change in the mainstream reductionist research paradigm, to give more consideration to the overall level of things. The complex systems album, released in April 1999 by the U.S. "Science" magazine, entitled "Beyond reductionism" showcasing the progress in this field of study of complex systems.

Systems science as the theoretical basis of the optimal allocation of water resources systems, should be absorbed and the application of these new theories and methods, so as to promote itself to the formation of the new development.

The paper used the theories and methods of complex adaptive systems, analysis of regional water resources optimal allocation system, designed the resources optimal allocation model, and simulation experiments were performed and the algorithm is employed to allocate the water resources of the Ningxia Hui Autonomous Region in northern China where water shortage cannot be avoided due to the rapid growth in water demand.

2. THE COMPLEXITY OF THE OPTIMAL ALLOCATION OF WATER RESOURCES

The water resources system is an open complex system. Water resources and its optimal allocation of complexity are determined by objective and subjective complexity of two parts.

Objective complexity arises from the characteristics of the water resources system itself, mainly in the following aspects:

(1) Openness. The water system is open, with the matter, energy, information exchange system between the external environments. This both inside and outside the exchange, prompting the system environment are constantly changing, evolution from one state to another state, leading to the complexity of the system evolution. (2) Multi-level. Water resources involving climate, hydrology, geography, ecology, social, economic and many other subsystems, and any one subsystem contains a number of elements and the next level subsystem, to form a large multi-level structure. (3) Nonlinearity. The water system is made up of a number of elements or subsystems, the various elements or subsystems interconnected and mutual restraint, resulting in a complex non-linear relationship by one or more ways, it is the main source of water resources system complexity. (4) Uncertainty. The uncertainty stems from the water resources system with a large number of random fuzzy factors(such as meteorology, hydrology, water demand), resulting in system development unpredictability.(5) Dynamics. The water system is always in change, over time, the system structure, function, and behavior changing to the more advanced evolution by self-adaption and self-organizing.

Subjective complexity is mainly due to the complexity of the human society, water resources is an integral part of the development of human society, it is a natural - artificial binary system, closely related to the human society. In the process of use of water, human naturally involved in this circulation system, and to exert influence through its own force of the water resources. Human society itself is an extremely complex system; the contact between the water system with the human society is complex. One hand may be complementary and promote each other; the other side may be mutual restraint, mutually constraints. The framework of optimal allocation of water resources is shown in Figure 1.

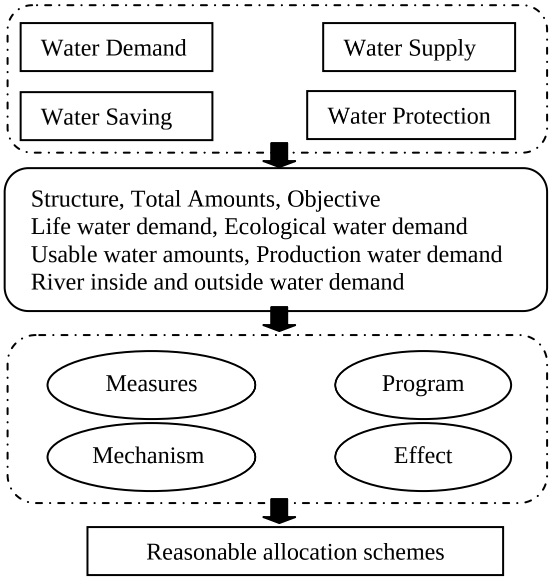

Figure 1: The framework of optimal allocation of water resources

Through analysis, the subjective complexities include the following aspects:

(1) On the management of the water complex multi-level structure. Optimal allocation of water resources system with a multi-level structure itself is complex system engineering, coupled with the asymmetry of the system structure, the optimal allocation of water, water resources management decision-making and control has a prominent nonlinearity and uncertainty, which adds the complexity of the water resources allocation and management a certain extent.

(2) The behavior management of complex elements or subsystems. Water system is composed by a number of different sizes of elements or subsystems, the behavior of the elements or subsystems have water supply, water, and maintain complex ecology, pollution, water quality protection, flood and drought control, power generation and other activities. Carried out for the management of these behaviors are usually based on human-centered, then, in this process, personality differences, the level of decision-making level, the degree of accumulated experience, knowledge reserves and other factors inevitably

affect the realization of the management objectives. And sometimes, management behaviors deviate from target, because of the human factor.

(3) Water is a competitive resource. Water demand of elements or subsystems of water resources system (such as the number, importance and urgency) are not the same, more often pose directly contradictions.

(4) The open dynamic management derived complexity. The water system is open, dynamic, its optimal allocation activities must be open, dynamic, resulting in a dynamic and uncertainty on management decisions and measures. And the dynamics and uncertainties can not be fully predicted. Once the change, managers must make the adjustment on the decisions and actions accordingly. Moreover, in the management process, managers often in order to minimize the sudden change to continuously enhance the ability to predict, to develop plans to deal with more situations. Therefore, the process of adapt to changes continually increases the complexity of management.

3. OPTIMAL ALLOCATION OF WATER RESOURCES BASED ON COMPLEX ADAPTIVE SYSTEM THEORY

Optimal allocation of water resources system is a complex adaptive system, by use of the tools of the CAS, the characteristics of the optimal allocation of water resources analyzed as follows:

3.1 Agent, Adaptability, Rules

Optimal allocation of water system consists of agents; each agent has the initiative, adaptability, objectives, internal structure and survival power. Such as government, business, family, hydropower stations, reservoirs, sewage treatment plant. These agents interact with the environment, as well as other agent constantly "learning" and "accumulated experience" or "growth of knowledge", and be able to take advantage of the accumulated experience and knowledge to further change their structure and behavior in order to adapt to changes in the environment, coordinate with the other agents, so as to promote the development and evolution of the entire system.

The behavior of agents is determined by a set of rules, and these rules are consistent with a causal stimulus - response principle. IF stimulus occurred THEN respond. The behavior in the optimal allocation of water in the system is determined by such a set of rules. For example: IF insufficient rainfall THEN increased irrigation; IF sufficient rainfall THEN impounding, flood control, power generation.

In the process of optimal allocation of water resources systems modeling, the main work is to analyze, select and describe the relevant main stimulus and response rules.

3.2 Aggregation, Emergence

Aggregation refers to the agent through the "stickiness" to form larger aggregates, and that the aggregate is a high-level agent. Because the agent has this property, they can, under certain conditions, mutually acceptable to form a new agent- aggregate, which active in the system like a single agent. The role of the aggregation is to promote the agents bonded together, and interacted, thus emerged a complex, large-scale behavior.

For example, farmers in agricultural production, individual farmers is a simple water main, it has a limited capacity. When encountered greater environmental changes, its viability, adaptability, and the rules of conduct will be met with strong challenges, and even damaged. However, when a large number of farmers gathered to form the rural water users association, its viability, adaptability is completely different, there are significantly enhanced. And the rural water users associations emerged more powerful behavior. For example, in the construction of irrigation management, financial management of water charges, water conservation, drought drainage, irrigation facilities maintenance will be showing the amazing energy, coherence and coordination. The agent and system evolution process of the optimal allocation of water resources is shown in Figure 2.

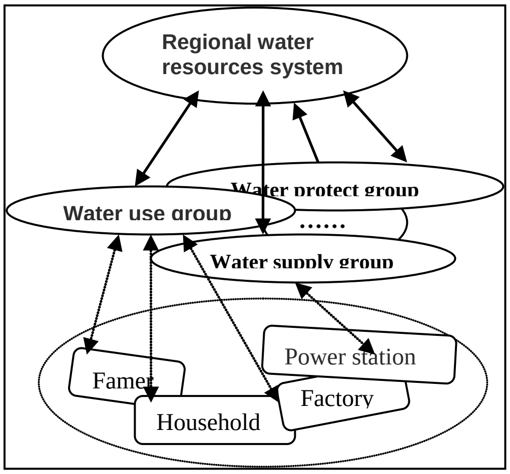

Figure 2. The agent and system evolution process of the optimal allocation of water resources

3.3 Nonlinearity

In a complex adaptive system, the relationship between the agents is complex. The effect of this relationship is often not equal to the sum of the individual effects of the linear relationship.

The optimum allocation of water resources system has very obvious nonlinearity, for example, the price of water and water consumption, water consumption and economic effects are non-linear relationship.

3.4 Flows

Flows refer to the flow of matter, energy, information and other resources between nodes of a complex network of inter – agents. Whether these stream channels are smooth, quick, have a direct impact on the process of evolution of the system.

The optimal allocation of water resources system have material flow, information flow which involving water demand forecasts, supply and demand information to pass on the water regime, water quality, water quantity monitoring and early warning; capital flow which involving the price of water and income distribution in the water market.

3.5 Diversity

The interaction of agents and the continuous adaption process each other, caused the agent to be different, so as to make the difference; with the difference in expansion, and eventually formed the diversity.

The diversity of optimal allocation of water resources system is very rich: different irrigation, different cities, different industries and different nature of the ecotope different; in the group with water demand difference is obvious; Water supply group of individuals water supply capacity, water supply way are different.

3.6 Internal Model (Mechanisms)

The internal model procures the agents to be able to predict what will happen when encountered the mode or similar mode again. That includes implicit model and explicit model.

In the water resources complex adaptive system, whether the independent agent or departments have their own internal models, these internal models influence their decision-making process. Household water use behavior more dominated by the implicit internal model. Water allocation plan, forecast water demand, more influenced by explicit internal model.

With the shortage of water resources, water prices are gradually raising, the family in order to save expenses had more planned water. In this case, the water acts by explicit internal model of domination. Overall, the internal model of the main water resources complex adaptive system is both implicit explicit.

3.7 Building Blocks

A complex system often consists of a number of relatively simple building blocks, by changing the combinations formed.

From the physical makeup of the water resources complex adaptive system, the people are the basic building blocks of the system. Different people have different physical characteristics, character, ability and expertise. They are combined in different ways to produce the system to take on different tasks, play different roles to complete different functions of the unit, organization or sector(For example： Rural Water Association, Water Station, Channel Management Department, Irrigation Authority). These units, organizations or departments should be combined in an appropriate way, so that the social and economic system to function effectively.

3.8 Tagging

A tagging is used for mutual identification and selection, as the interaction of the agent with the other main or environment. There is a large number of tagging in water resources complex adaptive system, such as the high water consumption enterprises, low water consumption enterprises, drought-resistant crops, water-saving irrigation.

4. THE AGENT MODELING OF THE OPTIMAL ALLOCATION OF REGIONAL WATER RESOURCES

For the water system, the classification of the agent in accordance with the type of water users；The classification criterion is not entirely consistent, and along with the deepening of the understanding of water resources systems, is also changing.

In order to maintain the consistent connotation with the current classification standards of the majority of water users in China, and to adapt to the sustainable use of water resources, we divided the agent of the model, as shown in Figure 3.

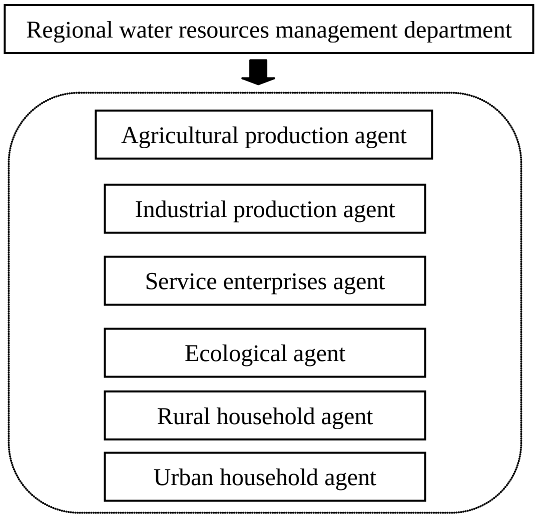

Figure 3. The agent model of the optimal allocation of water resources

All kinds of agents are described as follows:

The regional water resources management department is mainly responsible for the formulation of macroeconomic policy and coordination between the departments of water. Its decision-making objective is to maximize the benefits for society as a whole under the principles of sustainable development.

Under the regional water resources management department, there are six agents: agricultural production agent, industrial production agent, service enterprises agent, rural household agent, urban household agent, ecological agent.

Agricultural production agent: Its behavior includes adjusting irrigation area, changing the planting structure, implementing of water saving irrigation, optimizing the irrigation system, etc.

Industrial production agent and service enterprises agent: Their behavior, including water-saving transformation, water production, economic accounting, and maximizing economic benefits.

Rural household agent and urban household agent: The behavior of the family mainly includes water consumption, household production sewage.

Ecological agent: Including water environment, ecological environment and other economic and social environment, carrying capacity, etc.

In order to effectively evaluate the operational status of the agents, consider the model selected following several evaluation indicators:

1) Domestic water, including urban per capita water consumption (Tons / Person-Year); rural per capita water consumption, as well as the per capita water consumption.

$$F = 0.5W^{2} - 0.14(I/P - 100)^{0.5}W \qquad (1)$$

In the formula, W represent the household water quota, (m^3/Month-Person); I represents the household income, (Yuan/Month); P represents the water price, (Yuan/m^3); F represents the comfort of family life.

2) Economic growth indicators: considered the net economic benefits produced by water use in different industries in all sub-districts and level years.

$$\mathrm{E} = \max\left(\sum_{i=1}^{3} 10^{4} \square 1/K_i \square \sum_{j=1}^{n} x_{ij}\right) \qquad (2)$$

In the formula, the decision variable x_{ij} denotes the water consumption of different sources j distributing to different water users i ; $i = 1 \sim 5$, denote the five water users; $j = i \sim n$, denotes the number of water sources; the symbol k_1, k_2, k_3 denote the water consumption of three industries respectively, (m^3/10^{4}Yuan);E denote total output value,(10^{4}Yuan).

3) Water environment indicators: the objective is to guarantee ecological water demand and minimizes pollutant discharge. Ecological water can be used as one of the constraints, and an equation of minimizing pollutant emission is set up in the objective function.

The minimal contamination of COD and BOD discharge amount is used to represent water circumstance condition.

$$C = \sum_{k=1}^{K} \sum_{j=1}^{J(K)} [0.01 d_j^k p_j^k (\sum_{i=1}^{I(K)} x_{ij}^k + \sum_{m}^{M} x_{mj}^k)] \qquad (3)$$

In the formula, p_j^k denotes waste water discharge rate of user j in sub district k ; d_j^k represents the amount of COD and BOD in sub district k wastewater (mg/L).

This process can also be verified from the side, the CAS theory applied to the feasibility and rationality of the water resources allocation and management.

5. THE EXPERIMENTAL RESULTS AND ANALYSIS

The Ningxia Hui Autonomous Region located in northwest China(Geographical coordinates: east longitude 104 ° 17 '~ 107 ° 39', latitude 35 ° 14 '~ 39 ° 23'. North and south about 465 km long, wide things about 45-250 km) and covering some 60,000 square kilometers, Ningxia is home to six million people. One third of the population is ethnic Hui minority. With the Yellow River passing through the region, Ningxia enjoys a convenient irrigation system. There are numerous rivers, lakes and channels in the region. Ningxia is one of China's major agricultural areas. The study area includes Yinchuan City, Shizuishan City, Wuzhong City, Guyuan City and Zhongwei City.

Ningxia few precipitation, evaporation strongly, and the air is dry. For many years, the average annual rainfall is 289 mm, from north to south increasing, change in 180~800 mm. In the water evaporation capacity 1250 mm, is 4.3 times of precipitation, the trends and precipitation instead, from north to south decline, change in 1600~800 mm. The above two contrary trend decided the difference between the north and the south is drought index, by southing north change in 1~9 between, most areas for 3~9, belong to an arid and semi-arid area.

The above model is applied to optimize the allocation of water resources in the Ningxia Hui Autonomous Region. Firstly, the total water supply should satisfy the demand of water users, and the economy object, population object and circumstance object are considered at the same time during allocating water source (included surface water and groundwater). In this paper, the water demands in 2010 (Table 1) is taken as the basis of the research, and the water demands in 2035 are regarded as the expected levels (Table 2, Table 3).

6. CONCLUSIONS

The theory of complex adaptive systems (CAS) is a modern system science enlightening noteworthy areas. CAS modeling and research has become a hot spot. From a new perspective, to absorb and use CAS theory to guide water resources optimal allocation is necessary.

The optimal allocation of water resources is an important content of Water science, because the system of water resource is multi-object, so it’s difficult by using traditional method to solve this problem. In this paper, the CAS theory is used to solve the problem. The case study shows that the result of differential evolution is both reasonable and efficient. It is very convenient for practical use since the will of the policy-maker can be adjusted at any time according to the specifics of the problem in question.

ACKNOWLEDGEMENTS

This work was financially supported by the Ministry of Education Innovation Team of China ([2011]20)；the crucial project of the 11th five-year period of Ningxia ([2006]05)；the Natural Science Foundation of Ningxia，China (NZ12123)；The Natural Science Foundation of Ningxia University (ZR1120).

REFRENCES:

[1] R. Storn, K. Price, “Differential evolution - A simple and efficient adaptive scheme for global optimization over continuous spaces,” Berkeley: University of California, 2006.

[2] ZHOU Ming, SUN Shu. Genetic algorithm and its applications [M]. Beijing: National defense industry press, 1999.

[3] CHEN Yong-Ming, LIN Ping, HE Yong. Study on discrimination of producing area of olive oil using near infrared spectra based on genetic algorithms [J]. Spectroscopy and spectral analysis, 2009, 29(3):672~674.

[4] ZHANG Qiang, WANG Bin, ZHANG Rui, etc. Genetic algorithm-based design for DNA sequences sets [J]. Chinese journal of computers, 2008, 31(12):2193~2199.

[5] S.Y. CHEN, “Fuzzy optimization theory and its applications of multi-stage and multi-objective decision-making system,” Journal of Water Resources, vol. 1, 1990, pp. 1-10.

[6] W.Q. GU, D.G. SHAO, X.F. HUANG, and T. DAI, “Multi-objective risk assessment on water resources optimal deployment,” Journal of Water Resources, Vol.39, No. 3, Mar. 2008

[7] Wang Huimin. Theory and Method on Sustainable Development System of River Basin [M]. Nanjing: HoHai University Press, 2000.

[8] Zhao Yong, Xie Jian cang, etal. Water dispatch of east2route of south2to2north water transfer project based on system simulation method [J].Journal of Hydraulic Engineering, 2002 (11):38 - 43.

[9] Kumar, Arun Minocha, and Vi Jay K, “Fuzzy optimization model for water quality management of a river system” Journal of Water Resources Planning and Management,vol. 125, 1999, pp. 179-180.

Table 1: Water demand of Ningxia in 2010 (Unit: 10^4m^3)

City	Primary industry	Secondary industry	Tertiary industry	Town	Country
Yinchuan	143458	69597	26545	4968	1023
Wuzhong	56431	24734	8245	1884	974
Zhongwei	63664	31577	10526	767	984
Shizuishan	55234	25582	8427	1783	541
Guyuan	15645	6748	2043	548	1753

Table 2: Results of optimal allocation of water resources in 2035 (50%) (Unit: 10^4m^3)

City	Item	Primary industry	Secondary industry	Tertiary industry	Town	Country
Yinchuan	Water demand	168685	84332	28111	6199	3193
	Water supply	172997	86492	28831	6199	3193
	Water shortage	0	0	0	0	0
Wuzhong	Water demand	53655	44713	14904	3198	1371
	Water supply	92017	46009	15336	3198	1371
	Water shortage	0	0	0	0	0
Zhongwei	Water demand	78595	39298	13099	2290	981
	Water supply	81187	40594	13531	2290	981
	Water shortage	0	0	0	0	0
Shizuishan	Water demand	67297	33649	11216	2862	1227
	Water supply	70753	35337	11792	2862	1227
	Water shortage	0	0	0	0	0
Guyuan	Water demand	12071	6036	2012	2973	1274
	Water supply	12071	6036	2012	2973	1274
	Water shortage	0	0	0	0	0

Table 3:Results of optimizing allocation of water resources in 2035 (75%) (Unit: 10^4m3)

City	Item	Primary industry	Secondary industry	Tertiary industry	Town	Country
Yinchuan	Water demand	168663	84332	28111	6199	3193
	Water supply	168663	81651	28003	6199	3193
	Water shortage	0	-2681	-108	0	0
Wuzhong	Water demand	53655	44713	14904	3198	1371
	Water supply	536655	43109	14851	3198	1371
	Water shortage		1604	53	0	0
Zhongwei	Water demand	78595	39298	13099	2290	981
	Water supply	78595	39134	12991	2290	981
	Water shortage	0	164	108	0	0
Shizuishan	Water demand	67297	33649	11216	2862	1227
	Water supply	67297	32421	11002	2862	1227
	Water shortage	0	1228	214	0	0
Guyuan	Water demand	12071	6036	2012	2973	1274
	Water supply	12071	5123	1952	2973	1274
	Water shortage	0	913	60	0	0