Study on Double-Level Allocation of Irrigation Water Rights

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Study on Double-Level Allocation of Irrigation water rights

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Abstract: Establishing and perfecting the water rights system is an important way to alleviate the shortage of water resources and realize the optimal allocation of water resources. Agriculture is an important user of water in various water-consumption industries, the confirmation of water rights in irrigation districts to farmers is the inevitable requirement for implementing fine irrigation in agricultural production. In this paper, a double-level water rights allocation model of national canals – farmer households in irrigation district is established. It takes into account the current water consumption of the canal system, the future water-saving potential and the constraint of total amount control at the canal level. It takes into account the asymmetric information of farmer households' population and irrigation area at the farmer household level. Furthermore, the Gini coefficient method is used to construct the water rights allocation model among farmer households based on the principle of fairness. Finally, Wulanbuhe Irrigation Area in the Hetao Irrigation Area of Inner Mongolia is taken as an example. The results show that the allocated water rights of the national canals in the irrigation district are less than the current because of water-saving measures and water rights of farmer household get compensation or cut respectively. The research has fully tapped the water-saving potential of irrigation districts, refined the distribution of water rights of farmers and can provide a scientific basis for the development of water rights allocation in irrigation districts and water rights transactions between farmers.

Key words: Gini coefficient; Fairness principle; Irrigation district; Double-level; Water rights allocation

1. Introduction

The initial allocation of water rights is the first step in the construction of water rights system and the key measure to carry out water rights trade and give play to the function of optimal allocation of market resources. Based on the experience at home and abroad, the modern water rights system can be divided into riparian right system, priority occupancy right system and public water distribution right system according to the initial acquisition and distribution forms of water rights (Zheng et al. 2012). Currently, China implements an administration-led public water rights allocation system (Guo 2009). The distribution system is generally from top to bottom, which distributes the initial water rights in a basin to provinces, cities, counties, industries and final water users (Wu et al. 2017).

At present, the initial distribution of water rights is mainly concentrated on the distribution from a basin to regions and industries. It is a multi-objective and multi - level distribution problem that the water rights obtained by provinces are further allocated to cities and counties. Generally, the index system is established from three aspects of economy, society and ecology, and the weight is calculated. In terms of processing methods, fuzzy optimization, Critic method (Li et al. 2012) and entropy weight TOPSIS method abandon the shortcomings of strong subjectivity and arbitrariness of traditional index analysis methods, and projection pursuit technology is also in the exploration stage (Diao et al. 2017). When the superior water rights allocation method is applied to the county level, there are problems such as large differences in water use among towns, inapplicability of the allocation index system and difficulty in collecting specific data. The water rights allocation results of the improved mutation model are more in line with the actual water use conditions (Rao et al. 2019). The second layer of allocation of water rights, that is, the allocation among industries, follows the principle of priority under the constraints of total amount control and "three red lines" to construct a target planning model based on the principles of priority of domestic water, food security, attention to ecological environment, economic benefits and reasonable industrial structure (Wu et al. 2012). At first, meet the domestic water needs of urban and rural residents, followed by industrial water with high water efficiency, followed by basic ecological water, and finally consider the demand for agricultural water. Based on multiple uncertainties and complexities such as dynamic water demand, adjusted water rights trading, and decision-makers' precise risk attitudes, it is the future trend to establish a stochastic correlation chance multi-objective programming model (Li et al. 2019; Lin et al. 2005; Wang et al. 2005).

Agricultural water is mainly used for irrigation, the further allocation of water rights to irrigation water users is an inevitable requirement for the realization of refined agricultural water management. The current agricultural water distribution system takes the irrigation district as the minimum distribution unit. Although some scholars choose equity and efficiency indexes to allocate water rights among farmers

(Zhang et al. 2017), equity only considers the area of agricultural land and the actual irrigation area of agricultural land. Existing studies have given little consideration to the asymmetry between the population of farmers and the irrigation area (Rijswick et al. 2015; Shapiro et al. 2015; Wu et al. 2017). In order to guarantee the fairness of agricultural water rights allocation, population and irrigation area should be comprehensively considered in the water rights distribution system for irrigation water users.

In this paper, according to the characteristics of multi-level water consumption in irrigation districts, a double-level water rights allocation model of national ZhiKou canals - farmer households in the irrigation district is established. The canal system water rights allocation considers the future water-saving potential of the irrigation district and determines the total amount of water rights allocated for canal system. Based on the characteristics of asymmetric information of farmer households' population and irrigation area, the water rights allocation among farmer households is carried out based on the Gini coefficient method, which fully considers the fairness of water rights allocation. Finally, Wulanbuhe Irrigation Area of Hetao Irrigation District of Bayannaoer City is taken as an example for verification based on the double-level water rights allocation model of the irrigation district constructed in this paper.

2. Materials and methods

2.1 Overview of the study area and data sources

2.1.1 Overview of the study area

Wulanbuhe Irrigation District is located in the west of Hetao Irrigation District of Bayannaoer City, and it mainly involves three administrative districts of Dengkou, Hangjin Houqi and Azuo Qi. The total population of irrigation area is 115100, including rural population of 69100, and the irrigation area is 68100 hm² in 2017. Wulanbuhe Irrigation Area belongs to the inland high plain of Hetao basin, located in the northeast of Wulanbuhe Desert. It belongs to the temperate continental monsoon climate, with four distinct seasons, abundant sunlight, large temperature difference and rare precipitation. The average annual precipitation is 144.5 mm, and the average annual evaporation is 2377.1 mm, which is 16.7 times the rainfall. Therefore, in order to satisfy the demands of agricultural water, Wulanbuhe Irrigation Area depends mainly on the Yellow River water for irrigation by Shenwu main canal, there are a total of 476 main canals and sub-main canals in Wulanbuhe Irrigation Area and of which 411 canals diverted directly from national canals are confirmed, because the water rights of the 411 canals will be distributed directly to the corresponding farmers, so this article focuses on the distribution of the Yellow River water rights for those canals in the irrigation district.

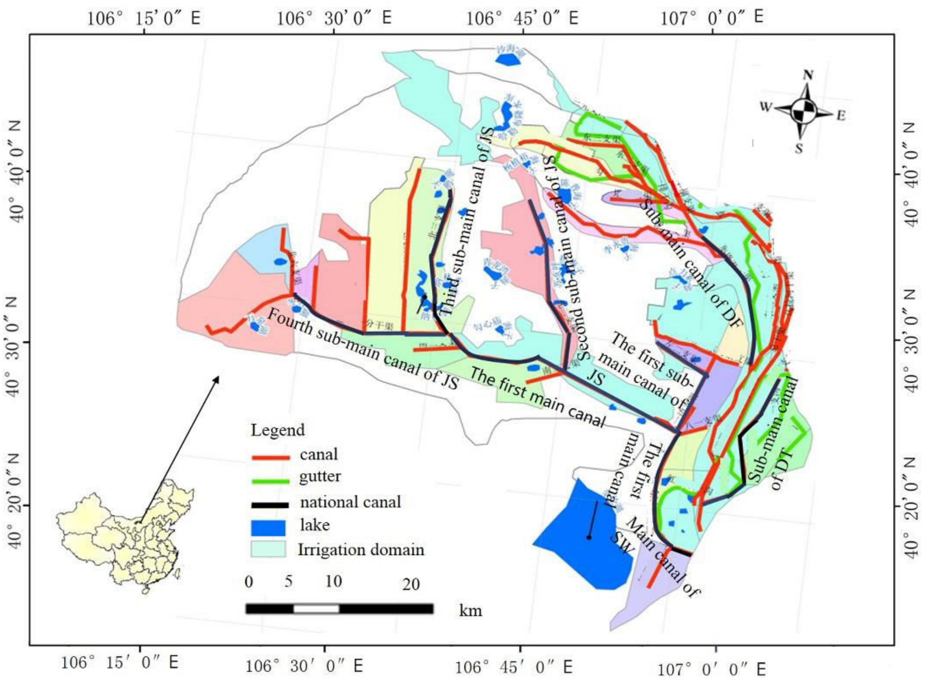

Fig. 1 Wulanbuhe Irrigation Area of Hetao Irrigation District

2.1.2 The data source

There are 411 canals diverted directly from national canals were confirmed in

Wulanbuhe Irrigation Area of Hetao Irrigation district, Bayannaoer city. Administration of Hetao Irrigation District has made statistics for the five-year water consumption of these canals in Wulanbuhe Irrigation Area from 2008-2013 (excluding 2012 due to water shortage than usual), and the data is true. According to the proposed plan of water-saving irrigation engineering, water-saving volume of the irrigation fields in the future can be calculated. The population and irrigation area of the corresponding farmer households in these canals are obtained from the actual statistical results of the township.

2.2 Double-level water rights allocation model of the irrigation district

Double-level water rights allocation model for the irrigation district includes the distribution method of water rights at the level of national canal system and the distribution method of water rights among farmer households. Taking the amount of water diversion from the main canal head of the irrigation district as the total amount of water rights allocation, firstly allocate water rights at the national canal system level, and then use those as the total for water rights allocation among farmers. Canal system structure diagram of irrigation district is shown in figure 2.

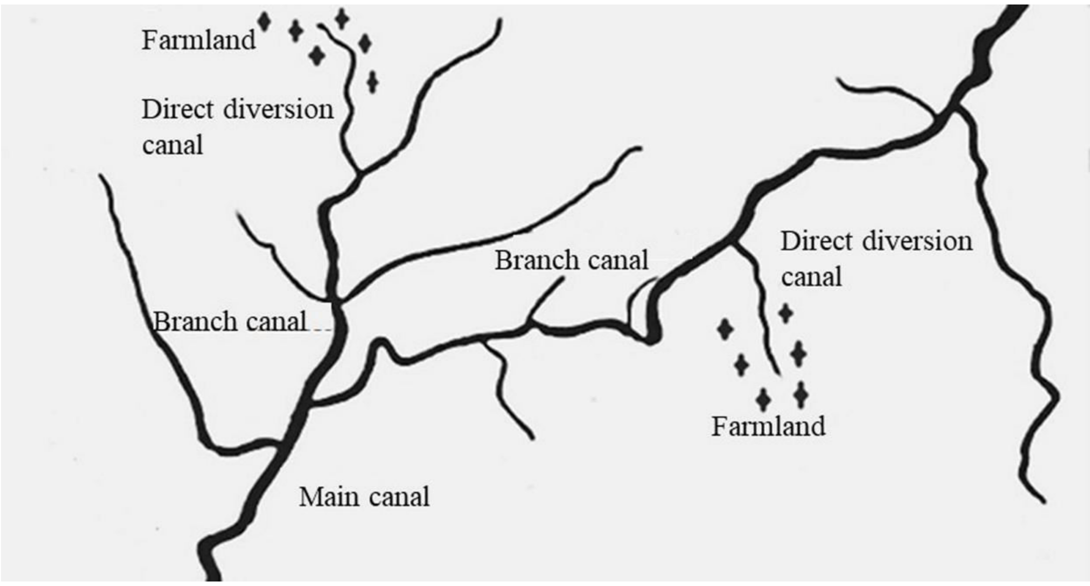

Fig. 2 National canal system structure diagram of irrigation district

2.2.1 Water rights allocation model of national canal system in irrigation district

(1) Total amount of current water rights at the national canal system level. Generally, the total amount of canal system water rights is determined by the actual water diversion in the irrigation district and the average water consumption over the years.

(2) Water-saving potential of the irrigation district. The main water-saving measures in the irrigation district are channel lining, border field reconstruction and drip irrigation. The total water-saving amounts of water-saving projects in the irrigation district is canal-level water-saving amount. The calculation formula is as follows:

Water saving amount of canal system:

$$\Delta W_i = \Delta W_{ic} + \Delta W_{iq} + \Delta W_{id} \quad (1)$$

Water saving amount of channel lining:

$$\Delta W_{ic} = W_i(1-\eta_i) - W_i'(1-\eta_i') \quad (2)$$

Water saving amount in border field reconstruction:

$$\Delta W_{iq} = W_{iqb} - W_{iql} \tag{3}$$

Water saving amount of drip irrigation：

$$\Delta W_{id} = W_{idb} - W_{idl} \tag{4}$$

where, ΔW_i is the water-saving amount of the channel *i*, ΔW_{ic}、ΔW_{iq}、ΔW_{id} are respectively the water-saving amount of channel lining, border field reconstruction and drip irrigation of the channel *i*, W_i、W_i' are respectively the canal head water intake before and after the lining of the channel *i*, η_i、η_i' are respectively the canal system water utilization coefficient before and after the lining of the channel *i*, W_{iqb}、W_{iql} are the field irrigation amount before and after the renovation of border fields of the channel *i*, W_{idb}、W_{idl} are the headwater diversion before and after drip irrigation reconstruction of the channel *i*.

(3) Distribution of water rights of national canal system. By analyzing the total amount of current water rights of canal system in irrigation district and considering the potential water saving amount of canal system in the future, the canal-level water rights allocation model is determined. The calculation formula is as follows:

$$W_{ip} = W_{is} - \Delta W_i \tag{5}$$

where, W_{ip} is the water rights distribution of the channel *i*, W_{is} is the total amount of current water rights of the channel *i*.

Due to the constraint of water diversion permit in irrigation districts, the total amount of water rights allocated at the canal level shall not exceed the permitted amount. Under the constraint of water intake permit, canal-level water rights allocation in irrigation districts is as follows:

When the allowable water intake is more than the actual total water diversion of each canal directly from national canal, that is:

$$\sum_{i=1}^{n} W_{ip} \leq W_{Q} \tag{6}$$

$$W_{ip} = W_{is} - \Delta W_{i} \tag{7}$$

When the allowable water intake is less than the actual total water diversion of each canal directly from national canal, that is:

$$\sum_{i=1}^{n} W_{ip} \geq W_{Q} \tag{8}$$

$$W_{ip} = \lambda_{ip} \times W_{Q} \tag{9}$$

$$\lambda_{ip} = \frac{W_{ip}}{\sum_{i=1}^{n} W_{ip}} \tag{10}$$

where, W_{Q} is the allowance of water intake in the irrigation district, λ_{ip} is the water distribution coefficient of the channel i.

2.2.2 Water rights allocation model among farmer households in irrigation districts

(1) Select the indexes of water rights allocation among farmer households

① Irrigation area of farmer households

Current agricultural water rights allocation is based on irrigation area. The larger the irrigation area, the more water rights are allocated. The distribution of water rights according to the irrigation area mainly reflects the difference of irrigation water of different farmer households, the distribution of water rights according to irrigation area is as follows:

$$S_{j} = q \times a_{j} \tag{11}$$

$$q = \frac{W_{ip}}{A_{i}} \tag{12}$$

where, S_j is the water rights of farmer household j distributed, q is the water rights allocation quota, a_j is the irrigation area of farmer household j, A_i is the irrigation area confirmed for all farmers in the canal system, W_{ip} is the water rights distributed of the canal i.

② Peasant household agricultural population

Water resources are the public resources of the whole society, so the distribution of water rights should give consideration to the development of all people, and the agricultural population of peasant households should be fully considered in the distribution of water rights. The household with more (less) agricultural population will get more (less) water rights. The distribution process is as follows:

$$S_j = q \times p_j \tag{13}$$

$$q = \frac{W_{ip}}{P_i} \tag{14}$$

where, S_j is the water rights distributed for farmer household j, q is the water rights allocation quota, p_j is the agricultural population of farmer household j, P_i is the agricultural population of all farmer households of the channel i, W_{ip} is the water rights distributed for the channel i.

(2) Water rights allocation model among farmer households based on Gini coefficient method

① Gini coefficient

Gini coefficient (Hu 2004; Cheng 2007), also known as Lorentz coefficient, was first proposed by Italian mathematician Gini at the beginning of the 20th century. It is mainly used in the field of economics to investigate and measure the inequality of regional residents' income and wealth distribution. It can more directly reflect the income difference between residents.

The value range of the Gini coefficient is [0,1]. When the Gini coefficient is 0, it represents the absolute average of income distribution. 0.4 is usually regarded as the warning line of income gap in the world, and the evaluation standard of Gini coefficient can be referred to the following table:

Tab. 1 Gini coefficient evaluation criteria

Gini coefficient	＜0.2	0.2～0.3	0.3～0.4	0.4～0.5	＞0.5
evaluation results	Absolute average	Comparative average	Relatively reasonable	Big gap	Wide disparity

② Construction of water rights allocation model by Gini coefficient method

When peasant household's water rights distributed based on irrigation area and based on farmer household's agricultural population are equal, the water rights allocation is considered to be fair. When the water rights allocated are not same, neither of the two distribution patterns can reflect the principle of fairness in the allocation of water rights, meanwhile, the irrigation area of farmer households and the agricultural population of farmer households are asymmetrical. In this article, therefore, the per capita irrigation area of each farmer is used as a measure of the fairness of water rights allocation, the theory of Gini coefficient is used to study the distribution relationship between irrigation area of farmer households and their agricultural population. With the cumulative percentage of the agricultural population of each farmer household in the canal system as the abscissa, the cumulative percentage of the irrigated area of each farmer household as the ordinate, the water rights allocation model was built based on minimizing Gini coefficient. The specific steps are as follows:

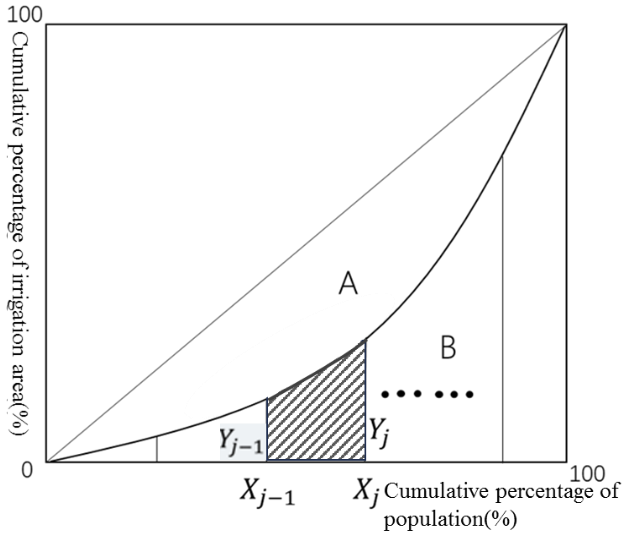

Fig. 3 Population - irrigation area Lorentz curve

Step1: Building the objective function

$$\min G_{ini} \tag{15}$$

$$G_{ini} = \frac{A}{A+B} = 2A = 1-2B = 1-\sum_{j=1}^{n}(X_j - X_{j-1})(Y_j + Y_{j-1}) \tag{16}$$

$$(Y_j - Y_{j-1})\ A_i = x_j \times (X_j - X_{j-1}) \times \tag{17}$$

Where, X_j is the cumulative percentage of agricultural population of farmer household *j*, Y_j is the cumulative percentage of irrigation area after equilibrium of farmer household *j*, P_i is the corresponding total agricultural population of the channel *i*, A_i is the corresponding total irrigation area of the channel *i*, x_j is the per capita irrigation area after equilibrium of farmer household *j*.

Step2: Setting Constraints:

a: Fairness constraints：

$$\begin{cases} x_j > x_j', & x_j < \overline{x}_i \\ x_j < x_j', & x_j > \overline{x}_i \end{cases} \tag{18}$$

Where, x_j is the per capita irrigation area after equilibrium of farmer household *j*, x_j' is the current per capita irrigation area of farmer household j, $\overline{x}_i$ is the per capita irrigation area of farmers of the channel *i*.

b: Constraints of basic water security:

$$\left|\frac{x'_j - x_j}{x'_j}\right| \le s \tag{19}$$

where, s is the reduction ratio determined by the degree of importance the region attaches to the principle of equity.

Restrictions on the extent of reduction or compensation:

$$\left|x_j - x'_j\right| \ge \left|x_\rho - x'_\rho\right|, \quad \left|x'_j - \bar{x}_i\right| \ge \left|x'_\rho - \bar{x}_i\right|, \quad j \ne \rho \tag{20}$$

c：Constraints of sorting:

$$x_{j-1} \le x_j \le x_{j+1} \tag{21}$$

d：Constraints on irrigation area:

$$\sum_{j=1}^{n} x_j \times p_j = A_i \tag{22}$$

where, p_j is the agricultural population of farmer household *j*, A_i is the corresponding total irrigation area of the *channel i*.

e：The Gini Coefficient after equilibrium is smaller than before:

$$G_{ini} < G'_{ini} \tag{23}$$

f：Non-negative constraints:

$$x_j > 0 \tag{24}$$

Step3: Determining the water rights of farmers distributed:

$$W_{jp} = \frac{W_{ip}}{\sum_{j=1}^{n} x_j \times p_j} \times x_j \times p_j \tag{25}$$

where, W_{jp} is the water rights of farmer j distributed, other symbols are the same as above.

Step4: Optimal solution of the model:

The model is optimized and solved by the genetic algorithm in MATLAB, and the calculation process of the optimized solution is as follows:

a：At the beginning of the genetic algorithm calculation, first set various parameters, such as setting the population size to 20, the number of iterations, the probability of crossover and mutation, and the termination conditions.

b：Generate the initial value group for the per capita irrigation area of farmers: $pop=[z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8]$.

Define fitness function: $G_{ini}=\left[1-\sum_{j=1}^{n}(X_j-X_{j-1})(Y_j+Y_{j-1})\right]$ and then calculate the fitness of the initial population, and compare the fitness value of the population.

c：Set the constraint conditions to see whether the fitness of the initial population meets the optimization criterion. If it is satisfied, the optimization ends; if not, proceed to step d.

d：Select, cross and mutate on the initial population pop, to produce offspring population pop_1, See whether the population pop_1 meets the optimization conditions. If it is satisfied, the optimization ends; if it is not satisfied, the selection, crossover, and mutation operations are continued until the conditions are met.

The optimization flowchart is as follows:

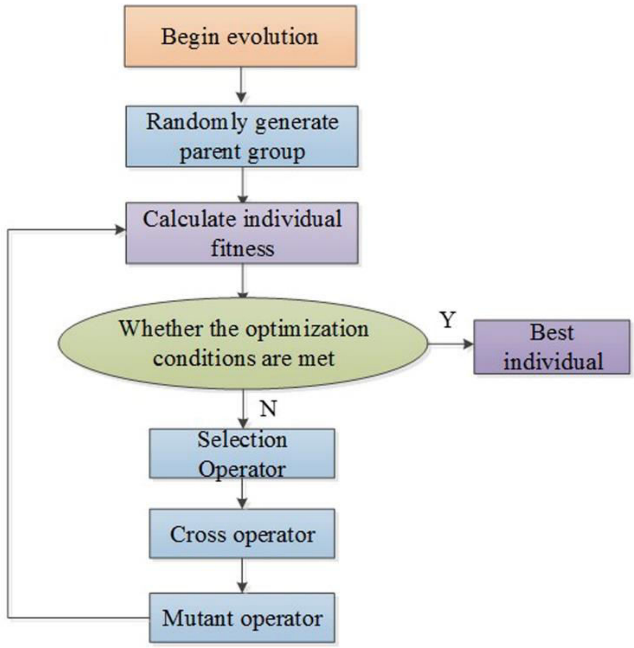

Fig. 4 Genetic algorithm optimization flowchart

3. Results and discussion

3.1 Results

3.1.1 Distribution results of water rights for the canals diverted directly from the national canal system

To allocate canal-level water rights for 411 canals diverted directly from the national canal system that need to be confirmed in Wulanbuhe Irrigation Area, according to current situation of water-saving projects in Wulanbuhe Irrigation Area, formula (1)-(4) are used to calculate the water-saving amount of the 411 canals. And then based on the five-year average water volume collected for the canals diverted directly from national canal system, formula (5) and formula (6) -(10) are adopted to calculate the distribution of water rights for the 411 canals. Take one of the 411 canals in Wulanbuhe Irrigation Area as an example for explanation, as shown in Table 2.

Tab. 2 Results of water rights distribution for canals diverted directly from national canal system in Wulanbuhe Irrigation Area

Direct diversion canal name	Township（farm）	Five-year average water volume	Water saving			Water rights allocation
			Water saving in channel lining	Water saving in border field reconstruction	Water saving in drip irrigation	
Grazing team (4)	Bayangaole Town	2.03	0	0.73	0	1.30
Bayi canal	Wulanbuhe Farm	198.15	0	42.16	0	155.98
The fourth lateral canal	Hatengtaohai Farm	84.35	22.96	15.14	0	46.25
New third canal	Bayantauhai Farm	16.95	6.10	8.08	0	2.76
First canal of Four groups	Sun Temple Farm	33.67	0	26.44	0	7.23
Susan canal 1	Shajin Sumu	13.74	0	6.17	0	7.57
Two rounds of water 1	Experiment Bureau	35.42	0	12.24	0	23.18
Western third lateral canal	Narintaohai Farm	67.28	0	26.03	0	51.25
The fourth brunch canal	Baoergai Farm	563.30	146.32	0	200.96	216.02
Zhao Duozhi	Bayin Maodao Gacha	12.66	8.82	1.57	0	2.27
Loess file one	Bulongnao Town	21.39	0	0	3.68	17.71
Tuanjie branch canal	San Tuan Farm	304.98	80.83	0	32.88	191.27
First lateral canal	Longsheng Hezhen	36.51	0	7.00	0	29.51

3.1.2 Results of the water rights distribution among farmer households

Since the patterns of water rights allocation among farmer households for 411 canals are the same, the canal of Grazing team (4) in Bayangaole Town is taken as an example for calculation and analysis. The irrigation area and the agricultural population of farmer households are selected as the water rights allocation indexes under asymmetric information. On the basis of the calculation formula of Gini coefficient, the population of farmer households and the corresponding irrigation area data are arranged according to the per capita irrigation area from small to large. The calculation process is shown in Table 3.

Tab. 3 The relevant calculation results for the Gini coefficient under current condition

Farmer household number	Irrigation area（hm^2）	Agricultural population	Current per capita irrigation area （hm^2/person）	$(X_j - X_{j-1})*(Y_j + Y_{j-1})$
1	0.333	6	0.056	0.0107
2	0.533	8	0.067	0.0515
3	0.400	5	0.080	0.0572
4	0.333	4	0.083	0.0615
5	0.733	6	0.122	0.1267
6	0.933	7	0.133	0.2104
7	0.600	4	0.150	0.1531
8	0.467	3	0.156	0.1320
total	4.333	43		0.8032

According to the above calculation results, the Gini coefficient for the current distribution of water rights is 0.1968. The above data are substituted into the water rights allocation model among farmer households, and then the balanced per capita irrigation area for 8 farmer households of Grazing team (4) are determined through objective function equations (15)-(17) and constraint equations (18)-(24).

The current per capita irrigation area of farmer households which exceeds (falls short of) the average per capita irrigation area of the canal system, $\bar{x}$ =0.101 hm^2 /person, needs to be reduced (compensate). The fairness constraint is:

$$\begin{cases} x_1 \geq 0.056 \\ x_2 \geq 0.067 \\ x_3 \geq 0.080 \\ x_4 \geq 0.083 \\ x_5 \leq 0.122 \\ x_6 \leq 0.133 \\ x_7 \leq 0.150 \\ x_8 \leq 0.156 \end{cases}$$

A substantial reduction in the per capita irrigation area of farmer households will lead to a reduction in their allocated water rights. In order to ensure a certain amount of basic irrigation water for farmers, this paper sets the reduction ratio to 0.3, the basic water security constraint is:

$$\begin{cases} x_5 \geq 0.085 \\ x_6 \geq 0.093 \\ x_7 \geq 0.105 \\ x_8 \geq 0.109 \end{cases}$$

The more per capita irrigation area is above or below the average of canal system , $\overline{x}$ =0.101 hm^2 /person，the greater the degree of reduction or compensation is, that is, the degree of reduction and compensation is restricted as follows:

$$|x_8-0.156| \geq |x_7-0.150| \geq |x_1-0.056| \geq |x_2-0.067| \geq |x_6-0.133| \geq |x_5-0.122| \geq |x_3-0.080| \geq |x_4-0.083|$$

After the equilibrium, the per capita irrigation area of each farmer household still satisfies the ranking before the equilibrium, ensuring the fairness of the distribution of water rights among farmer households, that is, the ranking constraint is:

$$x_1 \leq x_2 \leq x_3 \leq x_4 \leq x_5 \leq x_6 \leq x_7 \leq x_8$$

Before and after the equilibrium, the total irrigation area of the canal system for water rights allocation does not change, that is, the irrigation area constraint is:

$$6x_1 + 8x_2 + 5x_3 + 4x_4 + 6x_5 + 7x_6 + 4x_7 + 3x_8 = 4.333$$

After the equilibrium, the Gini coefficient of the farmer households' agricultural population-irrigation area should be smaller than that before the equilibrium, to ensure that the distribution plan is fairer than the current distribution, that is:

$$G_{ini} \leq 0.1968$$

After equilibrium, the per capita irrigation area of each farmer household is greater than 0, that is, the non-negative constraint is:

$$x_i \geq 0 \quad (i = 1, 2, \ldots, 8)$$

The genetic algorithm in MATLAB is used to solve the model, and the per capita irrigation area of the 8 farmer households of the canal of Grazing team (4) is balanced. The balanced per capita irrigation area of the farmer households is shown in Table 4.

Tab. 4 The per capita irrigation area of each farmer household after equilibrium

Farmer household number	Area（hm^2）	Agricultural population	Per capita irrigation area of farmer household（hm^2/person）	Per capita irrigation area of farmer household after equilibrium（hm^2/person）
1	0.333	6	0.056	0.071
2	0.533	8	0.067	0.079
3	0.400	5	0.080	0.087
4	0.333	4	0.083	0.089
5	0.733	6	0.122	0.115
6	0.933	7	0.133	0.122
7	0.600	4	0.150	0.133
8	0.467	3	0.156	0.137
Total	4.333	43		

According to the canal-level water rights allocation method, the allocated water rights of the canal of Grazing team (4) is 13000 m^3. According to the per capita irrigation area of each farmer household after the equilibrium, combined with formula (25), the water rights distributed for each farmer household by the model is calculated. The current water rights of farmer households and the water rights distributed by the model are shown in Table 5.

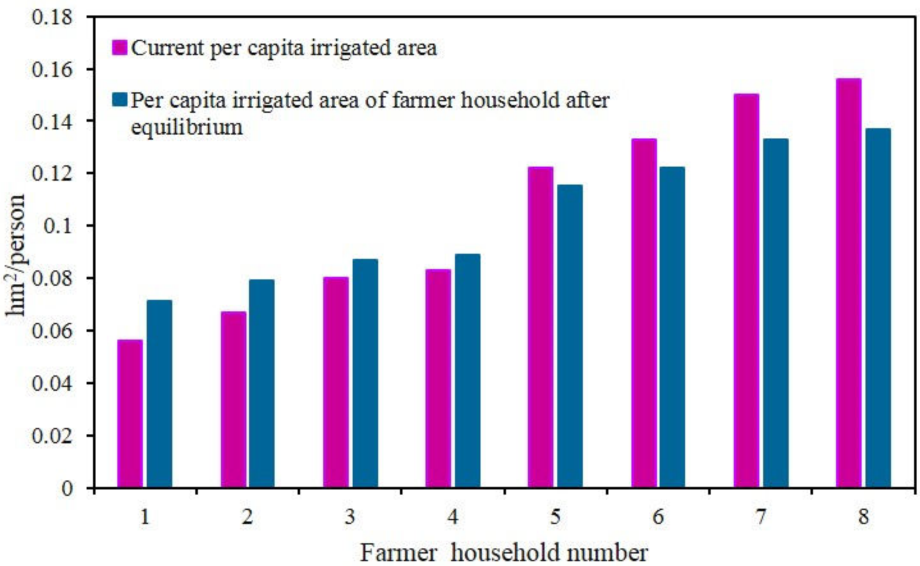

Fig. 5 Per capita irrigation area of farmer households before and after equilibrium

Tab. 5 The amount of water rights allocated by the model and the amount of current allocated water rights for farmer households unit: m^3

Farmer household	1	2	3	4	5	6	7	8
Water rights allocated by the model	1284	1888	1310	1072	2064	2562	1600	1230
Current allocated water rights	1000	1600	1200	1000	2200	2800	1800	1400

3.2 Discussion

3.2.1 Analysis of water rights distribution for the canals diverted directly from the national canal system

The current actual water consumption compared with the permitted water volume, the total water consumption volume of canal system in Wulanbuhe Irrigation Area is 347.9529 million m^3 , which is greater than the 330 million m^3 permitted. The current water rights allocation needs to be adjusted.

After the completion of the water-saving project, the total amount of water rights distribution for the canal system can be reduced. The Wulanbuhe Irrigation Area mainly saves water through three water-saving projects of canal lining, border field reconstruction and drip irrigation. The future water-saving amount calculated of three water-saving projects is 77.641 million m^3 , 68.10 million m^3 and 22.40 million m^3 respectively. The total water saving in Wulanbuhe Irrigation Area is 168.0817 million m^3 .

According to the water rights allocation model of the national canal system, from the actual current water volume minus the water saving amount, the total amount of water rights allocated to the 411 canals is 179.8712 million m^3 , which is less than the permitted water volume, and there is a remaining water volume of 150.1288 million m^3. The remaining water can be traded for water rights to increase the efficiency of water resources utilization.

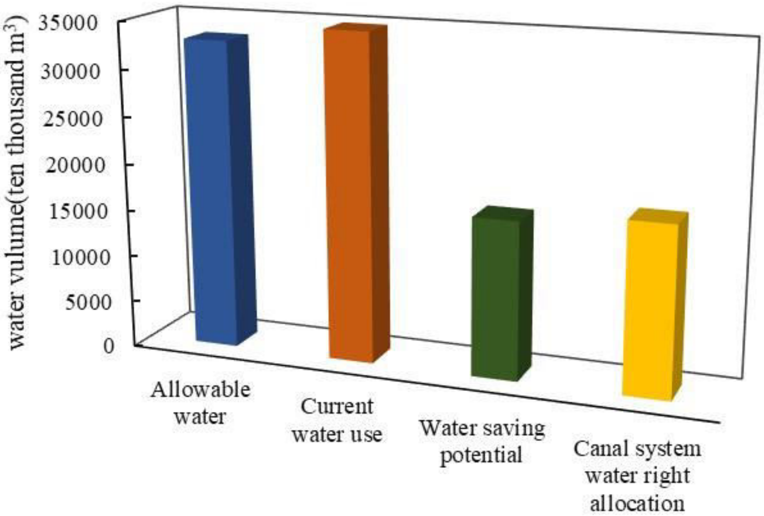

Fig. 6 Water rights allocation of canal system in Wulanbuhe Irrigation Area

3.2.2 Performance test of water rights allocation model among farmer house- holds

After the optimization of the model is solved, the Gini coefficient of the farmer household's population - the balanced irrigation area of the Grazing team (4) is 0.1289, which has been significantly improved compared with the Gini coefficient of 0.1968 of the farmer household's population - the current irrigation area, and the distribution of water rights among farmer households through the model is more equitable. Comparing the per capita irrigation area of farmer households after equilibrium by the model with that before, the compensation for farmers 1, 2, 3, and 4 is 0.0158 hm^2 /person, 0.0120 hm^2 /person, 0.0073 hm^2 /person and 0.006 hm^2 /person respectively, and the reduction for farmers 5, 6, 7, and 8 is 0.0075 hm^2 /person, 0.0113 hm^2 /person, 0.0167 hm^2 /person, and 0.0189 hm^2 /person respectively. The water rights distributed by the model for each farmer household have also been compensated or reduced accordingly compared to before. The amount of compensation (reduction) is shown in Figure 7.

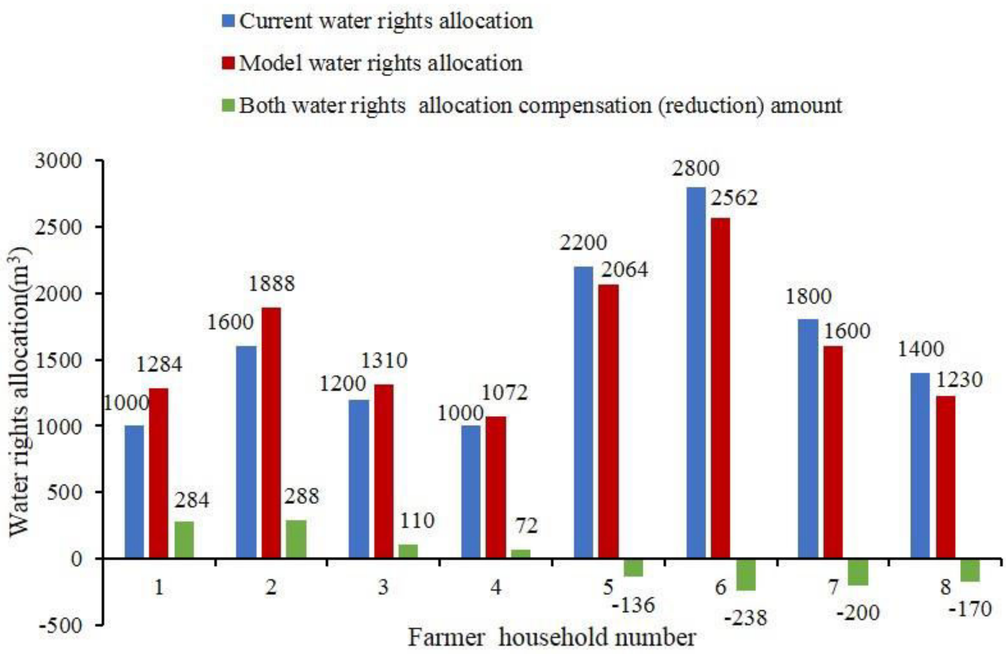

Fig. 7 Comparison chart of current water rights and water rights allocated by the model

According to the distribution results of the model, for farmer households with a small population and large irrigation area, such as farmer households 5,6,7,8, the water rights allocated by the model are less than the current allocation. As their irrigation needs cannot be met, they can adjust planting structures or obtain additional water rights through water rights transactions. For farmer households with a large population and a small irrigation area, such as farmer households 1, 2, 3, 4, the water rights allocated by the model are 754 m^3 more than the current allocation when only the irrigation area is considered. The allocation results by the model take into account the asymmetric factors of farm household population and irrigation area, and is more equitable. For example, the current water rights distributed for farmer household 1 and farmer household 4 are both 1000 m^3 , but the water rights allocated by the model are 1284 m^3 respectively and 1072 m^3. The water rights distribution model among farmer households established in this paper is fairer in the water rights allocation process, and to a certain extent can alleviate the contradiction between farmers and water distribution managers. After the establishment of the farmers' water rights market, farmers with more water rights voluntarily sell water rights, while farmers with fewer water rights voluntarily purchase water rights, which provides an opportunity to carry out water rights transactions among farmers in irrigation areas.

3.2.3 Overall Analysis of Water rights Distribution in Irrigation District

The results of the water rights distribution at the national canal system level and among farmer households calculated by the double-level water rights allocation model show that the total amount of water rights allocated for each canal in the irrigation district has been greatly reduced, which will inevitably lead to a relative decrease in the water rights distributed for farmers in the irrigation district. Therefore, the government should strengthen the implementation of water-saving projects, and the farmers themselves need to implement field water-saving measures, such as adjusting the planting structure and adopting high-efficiency water-saving irrigation technologies.

4. Conclusion

This paper establishes a double-level water rights allocation model of canals - farmers in irrigation district. The canal-level water rights allocation model is based on the future water saving of the canal system in the irrigation district; the famer-level water rights allocation model is set up based on the Gini coefficient method to deal with the problem of water rights allocation under the asymmetric information of the agricultural population and irrigation area of the farmer households. The canal-level water rights are reduced by the model compared to the five-year average water rights, but the basic characteristics of the irrigation land controlled by the canal system are different, and the water-saving potential is different, so the distributed water rights at canal-level have been reduced by different degrees than before. The distribution of water rights among farmer households mainly compensates the water users whose per capita irrigation area is less than that of the canal system. At the same time, it reduces those water users' per capita irrigation area which is higher than that of the canal system, the degree of compensation (reduction) is different because of population and irrigation area of the farmer households.

The distribution of water rights at the canal-level pays more attention to the water-saving potential of the irrigation district. Government management agencies will strength the implementation of water-saving projects for arable land to promote the conservation and utilization of water resources and sustainable development. The distribution of water rights at the farmer-level in the irrigation district comprehensively considers the two basic factors of population and irrigation area to achieve the fairness of water rights distribution among peasant farmers.

Ethical Approval Informed consent.

Consent to Participate Informed consent.

Consent to Publish Informed consent.

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Conflict of Interest None.

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