RESEARCH OF INITIAL WATER RIGHTS ALLOCATION IN LONG-DISTANCE WATER TRANSFER PROJECT

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ABSTRACT

The long-distance water transfer project provides a high guarantee of water resources security for water-deficient area. The middle route of South to North water transfer project is a key project to mitigate water shortage in northern China to keep the sustainable development of the area. There are four provinces benefiting from the project and its initial water rights allocation has received widespread concern. To solve this problem, this paper proposes an index system which including target layer, criterion layer, index layer and solution layer. The criterion layer is constructed by the Three Red Lines based on the china's strictest water resources management and the index layer is composed of 11 indicators. Then, the projection pursuit (PP) model of initial water rights allocation is established and the genetic quantum algorithm (GQA) is brought into the model to solve the projection index function. And, the best projection value calculated in the model is regarded as the water proportion of the initial water rights allocation. At last, the proposed model is successfully applied to allocate the initial water diversion of all the net increase water supply in the middle route of South to North water transfer project. The results reveal that the index system and the model proposed in this paper have feasibility and effectiveness to a certain degree, and it provides a certain reference value for the initial water rights allocation in long-distance water transfer project.

Keywords: long-distance water transfer project；the middle route of South to North water transfer project；initial water rights allocation；genetic quantum algorithm (GQA)；projection pursuit (PP)

1. INTRODUCTION

The long-distance Water Transfer Project is a fundamental project that aims to optimize the allocation of water resources in order to obtain a better spatial distribution, and thus it is expected to contribute to the coordinated and sustainable socio-economic development and the water safety in water-deficient areas. However, there is ongoing debate in China about how to optimally allocate water resources across multiple administrative regions along the water transfer route. In 2011, the Ministry of Water Resources of the People's Republic of China issued the most stringent water resources management system, in which "Three Red Lines" were set to control water resources development and utilization, water use efficiency and water pollutants in water function areas. It is suggested that in order for this policy to be effectively implemented, the market should play a fundamental role in water resources allocation by the proper design and implementation of the water right system. Thus, attention should be called to the initial water right allocation in water-receiving regions along the long-distance Water Transfer Project. Although many attempts have been made to establish the allocation model based on the predetermined criteria (Lu and Huang, 2013; Xiao et al., 2012; Yang et al., 2014; Bennett, 2000; Hu et al., 2010) or the quantity and quality of water resources (Zhao, 2012; Wang et al., 2010; Luo et al., 2006), there is no report to date of the initial water right allocation along the long-distance Water Transfer Project under the most stringent water resources management. Here, the initial water right is taken to mean the water use right, including water-taking right, water use right and waste water discharge right, which are corresponding to the "Three Red Lines" stated in the most stringent water resources management policy. In what follows the initial water right refers to the initial water use right unless otherwise stated.

In this study, the initial water right allocation index system is proposed in accordance with the "Three Red Lines" of the most stringent water resources management, and then the projection pursuit (PP) model is established and the projection index function is optimized by using genetic quantum algorithm (GQA) to determine the proportion of the initial water right allocation. Finally, the model is used for initial water right allocation in the first-stage project of the middle route of South to North Water Transfer Project.

2. METHODOLOGY

2.1 The initial water right allocation index system based on the "Three Red Lines"

The initial water right allocation index system that takes into account the effects of the most stringent water resources management on the society, economy, environment and resources is established, and it is composed of a target layer, a criterion layer (3 criteria), a index layer (11 indexes) and a solution layer (m regions), as shown in Figure 1. The target layer A is at the top of the system responsible for setting the requirements of the system on a macro level; the criterion layer B consists of three criteria for controlling water resources development and utilization B_1, water use efficiency B_2, and waste water discharge in the function areas B_3, which indicate the effects of the most stringent water resources management on the water taking, water use and waste water discharge specified in the initial water right allocation; the index layer is composed of 11 specific indexes on different criterion layers, each of which can independently indicate the effect of a particular aspect of the most stringent water resources management on the initial water right allocation, and in practical applications can be substituted with the actual value in a given year for a given region; while the solution layer is composed of the water-receiving regions.

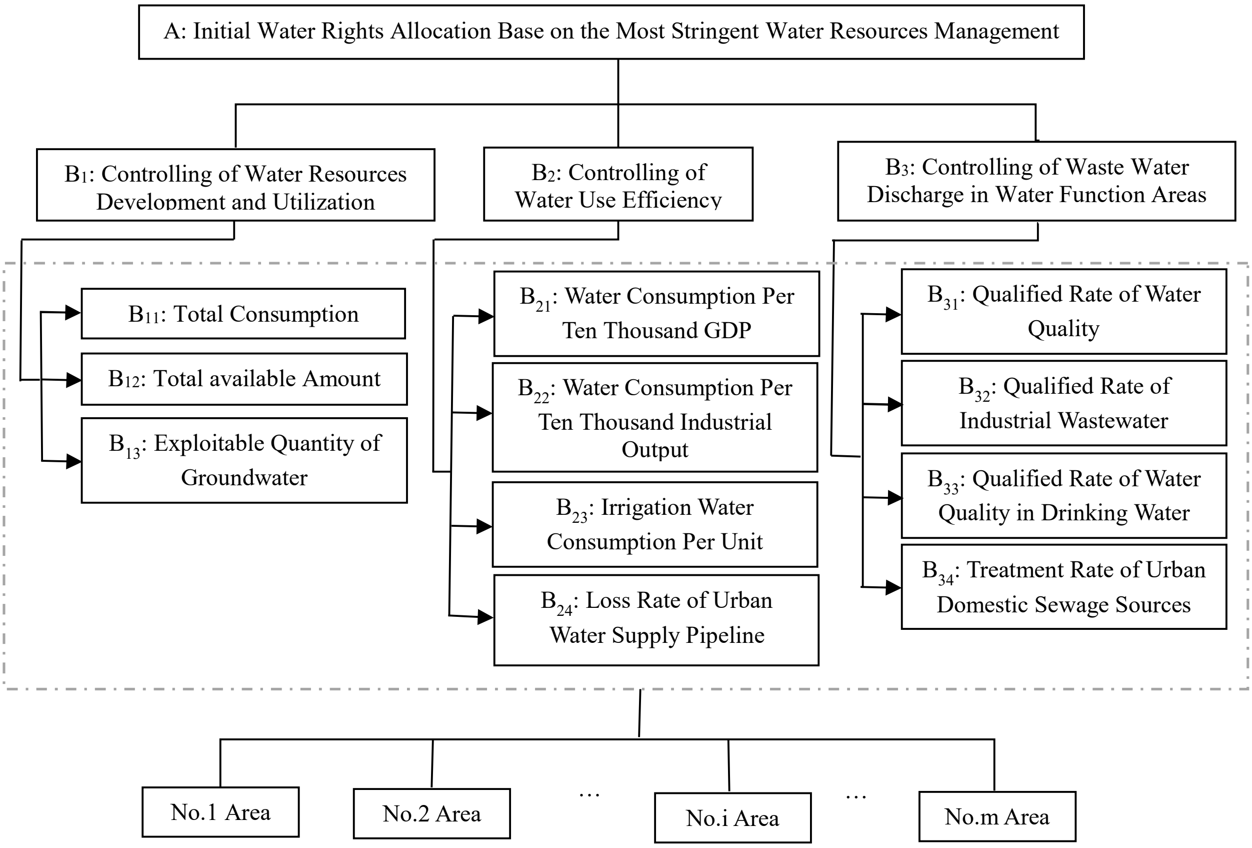

Figure 1. The initial water right allocation index system base on the most stringent water resources management.

2.2 The initial water right allocation model based on GQA and PP

The PP model is a complex nonlinear optimization problem that can hardly be solved by using traditional optimization methods. Despite its wide use in optimizing the projection direction, genetic algorithms are often criticized due to low convergence precision and even no convergence. Here, the GQA that combines genetic algorithm and quantum computation is used to solve the PP model due to its high convergence rate and precision and avoidance of premature:

(1) Normalization of the initial water right allocation index set. Let the sample set of each index be $\{x^*(i,j) | i=1,2,\cdots,n, j=1,2,\cdots,\mathrm{p}\}$, where $x^*(i,j)$ is the value of the index j in region i, n and P are the total number of regions and indexes. Due to the presence of multiple indexes for the initial water right allocation, extreme values should be normalized in order to eliminate the dimension and unify the change range of each index:

In the case where the larger the index value, the better the optimization results:

$$x(i,j)=\frac{x^*(i,j)-x_{\min}(j)}{x_{\max}(j)-x_{\min}(j)} \tag{1}$$

In the case where the lower the index value, the better the optimization results:

$$x(i,j)=\frac{x_{\max}(j)-x^*(i,j)}{x_{\max}(j)-x_{\min}(j)} \tag{2}$$

where, $x_{\max}(j)$ and $x_{\min}(j)$ are the maximum and minimum of index j, and $x(i,j)$ is the normalization sequence.

(2) Formulation of the index function $Q(a)$. In PP, the p-dimensional data $\{x^*(i,j)|i=1,2,\cdots,n, j=1,2,\cdots,\mathrm{p}\}$ are projected onto $a=(a(1),a(2),\cdots,a(p))$, which are unidimensional values $z(i)$ in the projection direction:

$$z(i)=\sum_{j=1}^{p}a(j)x(i,j)\quad,\quad i=1,2,\cdots,n \tag{3}$$

$$Q(a)=S_zD_z \tag{4}$$

where, a is the unit length vector, S_z is the standard deviation of projection values $z(i)$, and D_z is the local density of projection values $z(i)$:

$$S_z=\sqrt{\frac{\sum_{i=1}^{n}\left(z(i)-E(z)\right)^2}{n-1}} \tag{5}$$

$$D_z=\sum_{i=1}^{n}\sum_{j=1}^{n}\left(R-r(i,j)\right)\mu\left(R-r(i,j)\right) \tag{6}$$

where, $E(z)$ is the average of $\{z(i)|i=1,2,\cdots,n\}$; R is the window radius of the local density; $r(i,j)$ is the distance between samples in different regions, $r(i,j)=|z(i)-z(j)|$; $\mu(t)$ is the unit step function, which is 1 when $t\geq 0$ and 0 when $t<0$.

(3) Optimization of the projection index function by using GQA. For a given sample set of each index, the projection index function $Q(a)$ varies only with the projection direction a. Thus, the optimal projection direction can be estimated by maximizing the function $Q(a)$:

$$\max Q(a)=S_zD_z \tag{7}$$

$$s.t.\sum_{j=1}^{p}a^2(j)=1 \tag{8}$$

(4) Determination of the initial water right allocation proportion for each region. The optimal projection direction a^* is substituted into Eq. (6) to obtain the optimal projection values $z^*(i)$, which are normalized to obtain the initial water right allocation proportion and then multiplied with the total water amount to obtain the initial water amount for each region.

3. CASE STUDY

3.1 Study area

The middle route of the South to North Water Transfer Project is a strategic infrastructure in an attempt to alleviate the shortage of water resources in arid Northern China. The project is designed to divert 14.14 billion m^3 of water per year from the Danjiangkou reservoir in the middle and upper reaches of the Han River, the largest tributary of the Yangtze River, to Henan, Hebei, Beijing and Tianjin that would benefit 14 large and medium-sized cities along the route. The total water supply area is approximately 155000 km^2, and the total length of the main canal is 1432 km (including a 155-km tributary canal for diverting water to Tianjin). The total amount of diverted water is 9.5 billion m^3 per year for the first-stage project and 13 billion m^3 per year for the second-stage project, respectively. The proposed initial water right allocation model is used to calculate the water diversion amount in 2018 for the first-stage project under the most stringent water resources management, which is compared with the allocation amount of Henan, Hebei, Beijing and Tianjin in order to verify the feasibility and effectiveness of the proposed model. The major water receiving regions include (1) 12 regions (Diaohe irrigated area, Nanyang, Luohe, Zhoukou, Pingdingshan, Xuchang, Zhengzhou, Jiaozuo, Xinxiang, Hebi, Puyang and Anyang) in Henan province; (2) 7 cities (Handan, Xingtai, Shijiazhuang, Henshui, Baoding, Langfang and Cangzhou) in Hebei province; (3) Beijing; and (4) Tianjin. As these four regions show dramatic intra-regional differences in natural environment and socio-economic development, the average level of each water-receiving region in 2018 is considered in this study.

3.2 Determination of the initial water right allocation index system

Let the scheme set of the initial water right allocation be $V=\{v_1,v_2,\cdots,v_m\}$ ={Henan province, Hebei province, Beijing, and Tianjin}. The index values of the initial water right allocation are shown in Table 1.

Table 1. The index values of the initial water right allocation in the first-stage project of the middle route of South to North Water Transfer Project

Criteria	Indexes	Areas			
		Henan province	**Hebei province**	**Beijing**	**Tianjin**
B_1	B_{11} (10^8 m^3)	114.1	119.4	39.3	28.4
	B_{12} (10^8 m^3)	165.2	77.9	35.5	17.6
	B_{13} (10^8 m^3)	91.4	68.3	21.1	7.3
B_2	B_{21} (m^3)	36.7	50.7	13.0	15.1
	B_{22} (m^3)	25.9	13.9	7.5	7.8
	B_{23} (m^3/Mu)	155.0	176.0	131.0	210.0
	B_{24} (%)	17.0	14.0	10.0	10.0
B_3	B_{31} (%)	63.5	65.2	78.7	79.3
	B_{32} (%)	40.0	38.3	85.0	87.0
	B_{33} (%)	100.0	100.0	100.0	100.0
	B_{34} (%)	95.0	95.0	99.0	99.0

3.3 Solution of the initial water right allocation model

The indexes of each region are normalized, and then the projection index function is formulated and solved by using GQA to obtain the optimal projection direction, where the population size is set to 100, the quantum bit is set to 6, the mutation probability is set to 0.05, and the initial rotation angle is set to 0.05π, respectively. The program is executed in MATLAB and the optimal solution, a^* = (0.2261, 0.1322, 0.1820, 0.2143, 0.3454, 0.1833, 0.3845, 0.2345, 0.2532, 0.3075, 0.2461), is obtained after 38 iterations. Then, the optimal projection direction a^* is substituted into formula (3) to obtain the projection values $z^*(i)$= (14.632, 13.094, 6.389, 5.325) for the initial water right allocation under the most stringent water resources management, which are normalized to obtain the proportion of the initial water right allocation and then multiplied by the annual water diversion amount (95 hundred million m^3) to obtain the water allocation amount for each water-receiving region, as shown in Table 2.

Table 2. The scheme of the initial water right allocation in the first-stage project of the middle route of South to North Water Transfer Project

Scheme	Projection Values	Proportion of the Initial Water Right Allocation (%)	The Initial Water Diversion Amount (10^8 m^3)
Henan province	14.632	37.1	35.24
Hebei province	13.094	33.2	31.55
Beijing	6.389	16.2	15.41
Tianjin	5.325	13.5	12.80

4. RESULTS

Table 2 shows that the initial water diversion amount is 35.24, 31.55, 15.41, and 12.80 hundred million m^3 for Henan, Hebei, Beijing and Tianjin, respectively. According to the Report on the feasibility of the first-stage project of the middle route of South to North Water Transfer Project, the planned water diversion amount is 37.69, 34.7, 12.4, and 10.2 hundred million m^3 per year, respectively. It is noted that the calculated results are generally in agreement with the requirements with only a slight deviation, which may be attributed to the inaccuracy of data. Given the difficulty in collecting accurate water diversion data of different provinces and cities, the average data are used and put into the model. The observed difference could be easily adjusted by water right trade once the water right market is established, which can contribute greatly to the optimal allocation of the initial water right under the most stringent water resources management.

5. CONCLUSIONS

In this study, the initial water right allocation index system that takes into account the “Three Red Lines” in the most stringent water resources management is proposed, and then the PP model is established and the projection index function is optimized by using GQA to determine the proportion of the initial water right allocation. Finally, the model is used for initial water right allocation in the first-stage project of the middle route of South to North Water Transfer Project. The calculated results are generally in agreement with the requirements with only a slight deviation, indicating the feasibility and effectiveness of the proposed model. It is important to note that the model is intended to guide the future initial water right allocation and determine the red lines according to the current level in each region. The limitations of the proposed initial water right allocation index system and model should also be noted. Given the substantial differences among basins and regions, the controlling indexes should be adjusted according to the actual situation for each region. Due to the limited availability of water diversion data, the initial water right allocation in 2018 is investigated in this study, and more studies are warranted to investigate the initial water right allocation in other years or regions if possible in order to provide more reliable evidence for the initial water right allocation of the long-distance Water Transfer Project.

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