Study on ecological and economic effects of land and water resources allocation in Sanjiang Plain

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Abstract: The pattern of groundwater usage and industrial development in the Sanjiang Plain remains a concern of Chinese government. In accordance with the Water Conservancy Planning of the Sanjiang Plain, this paper presents a Sanjiang Plain resources allocation model which is established to be used in controlling water, land, ecology and economy in consideration of 50%-level and 75%-level years, planting structure adjustment, industry development by 2020, and different transit water exploitation schemes. Lingo10 global optimization has been adopted in solving the model. The results show that by 2020 the output of three industries will increase to a certain degree, the grain yields will satisfy state demand, and regional service value will decrease dramatically. Such results provide theoretical basis and practical significance for instructing the development and exploitation of the Sanjiang Plain.

Keywords: Sanjiang Plain; Global optimization; Allocation model; Comprehensive regulation of water-land resources and ecology-economy

Introduction

As one of the important commodity grain bases in China, the Sanjiang Plain has its own peculiarities compared with others. It is located in the cold region, which holds the majority of China's wetlands, and therefore it bears dual tasks of ensuring food security and ecological security. Compared with the northwest region which boasts vast land but less water, and the southwest region which is abundant in water resources but scarce in land, the Sanjiang Plain has relatively abundant water resources and vast land, providing good conditions for agricultural production. In 2008, the Overall Planning of Jilin Province for Commodity Grain Production Capacity Building to Increase Yield by Billions Kilograms and the Planning for Grain Production Capacity of Billions Kilograms of Heilongjiang Province were proposed, striving to achieve grain production enhancement by 15×10^9 kilograms by 2015. To this end, the Sanjiang Plain, with its superior natural resources and conditions, has become the most important area for grain production. Currently, however, there are still some prominent issues that restrict the achievement of high and stable grain production and environmental protection goals. Specific issues are as follows: Unreasonable agricultural structure, resulting in low and unstable grain yields; shrinkage of wetland area, over-exploitation of groundwater and decline of groundwater level, leading to the declining wetland function, and aggravating contradiction between agricultural development and wetland protection; low-temperature groundwater as the irrigation water source causing high costs and low yields; insufficient water conservancy facilities leading to inefficient use of water resources; water pollution becoming increasingly serious. Accordingly, Ministry of Water Resources and Songliao Water Conservancy Commission put up the idea of "two transformations and one improvement" (that is to say, without developing the wetland and under the premises of maintaining the existing arable land area, increase grain production through

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transforming the dry lands into wet fields and changing the groundwater irrigation into surface water irrigation), which is of high strategic significance with the view of achieving a win-win outcome in terms of food security and ecological protection, while abiding by the development rule of the Sanjiang Plain.

In the course of achieving this strategic goal, the comprehensive ecological and economic benefits of the Sanjiang Plain must be considered and the existing area of wetlands shall not be reduced; agricultural planting structure should be optimized to tackle the water supply issue during transforming the dry lands to wet fields; water resources diversion of Heilongjiang River, Ussuri River and Xingkai Lake should be developed reasonably under a comprehensive model of diversion and water lifting to improve the water conservancy allocation; wetlands protection and commodity grain base construction should be carried out at the same time so that land and water resources can be used in a sustainable way, as well as the economic, social and ecological benefits of the Sanjiang Plain can be improved simultaneously. Hence, we need to carry out a study on integrated control of water and land resources as well as ecological and economic development in the Sanjiang Plain, and establish a model of land structure optimization and eco-economic allocation of water and land resources, targeting at the optimal ecology and economy conditions. This is especially important for stable and high production of grain, protection of wetland and realization of sustainable development.

1 Basic condition of groundwater system and industrial structure in Sanjiang Plain

The study area is located in the northeast of the Sanjiang Plain, between latitude 45°26′0″N-48°22′50″, longitude 131°43′20″E-134°46′40″. It starts from the southeast side of Lesser Khingan Mountains to the west, and extends to the Ussuri River to the east with the Heilongjiang River as its north boundary and Wanda Mountain as its south end, covering a total area of 69 000 km^2. There are three primary rivers within the area, namely, the Songhua River, the Heilongjiang River and the Ussuri River. The soil there can be mainly divided into five types: Dark brown soil, black soil, white pulp soil, meadow soil and swamp soil, and there is also a small amount of flooding soil and soda-saline soil distributed along the coast and in the saline meadow in the vicinity of Jiamusi and Fujin.

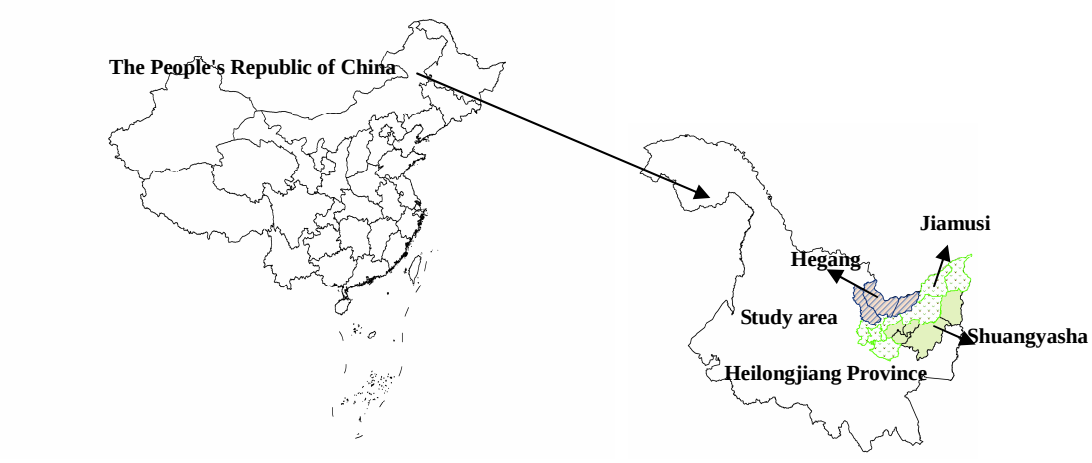

Fig. 1 Location map of for the study area

There are national level key protection wetlands distributed in the study area, which are also designated by the World Wetlands Convention Organization as the wetlands with global significance. By 2010, the area of the wetlands was 4 273 km^2.

The study area consists of three prefecture-level cities, namely, Hegang, Jiamusi and Shuangyashan, covering 15 counties (districts) in their jurisdiction. Hongxinglong Agriculture

Management Bureau, Baoquanling Agriculture Management Bureau and Jiansanjiang Agriculture Management Bureau and 34 farms managed by these bureaus are also located in the study area. In 2010, the GDP was 93.343×10^9 yuan, to which the primary industry contributed 28.633 billion yuan, accounting for 30.68%, the secondary industry contributed 31.61×10^9 yuan, accounting for 33.86%, and the tertiary industry contributed 33.1×10^9 yuan, accounting for 35.46%. In 2010 the total population was 5.132 million, of which the urban population was 3.0695 million, accounting for 59.86%; the rural population was 2.0624 million, accounting for 40.22%.

The main crops in the study area are rice, corn, and soybean. In 2010, the total grain output was 7.369×10^6 tons, of which the rice output reached 2.342×10^6 tons, accounting for 31.8% of grain output; the yield of dry crops was 5.027×10^6 tons, accounting for 68.2% of grain output. The region also boasts an important energy base of Heilongjiang Province, a Sino-Russia trade treaty port, two coal mining cities and coal-power-chemical base, Hegang and Shuangyashan, and Jiamusi, the regional center of culture, education, machinery manufacturing, electronics, textiles, paper, plastics, and food processing.

2 Eco-economic allocation model of water and land resources

2.1 Scenario settings

On the premise of ensuring constraint condition for the allocation model, to explore the allocation plan for the key regional development objectives under different circumstances by means of setting the following scenarios.

(1) In consideration of the impact of years with different water levels on the allocation model, this study provides the following levels, 50% (normal flow year) and 75% (medium dry year).

(2) In consideration of the planting structure adjustment, to set the upper and lower limits based on the status quo and scenarios specified in the Heilongjiang Grain Production Capacity Planning.

(3) In consideration of the situations corresponding to different levels of allocations, to carry out industrial restructuring based on the water use, water capacity, and economic development in 2020.

(4) To consider the effect of different transit water exploitation conditions on the allocation result.

2.2 Modeling principles

(1) In response to the national strategic plan, to optimize the layout of farming to ensure food production;

(2) To ensure long-term stable social and economic development;

(3) To protect wetlands and control groundwater exploitation;

(4) To improve water use efficiency and use the transit water rationally.

2.3 Selection of decision variables

In accordance with the general idea of the allocation model, after taking into account the major types of water consumption units and land use in the Sanjiang Plain, as well as the impact on economy, ecology and other aspects, we selected 22 decision variables, the classification and corresponding codes of which are as follows:

(1) Water resources decision variables and the corresponding codes (Unit: 10^4 m^3):

Urban domestic water consumption: s1, rural domestic water consumption: s2, agricultural water consumption: s3, industrial water consumption: s4, water consumption of the tertiary industry: s5, urban ecological water consumption: s6, wetland ecological water consumption: s7, surface water: dbs, groundwater: dxs, and transit water: gjs.

(2) Land resources decision variables and the corresponding codes (Unit: km^2)

Dry land: t1, paddy (high-yield): t2, paddy (low and mid-yield): t3, woodland: t4, grassland: t5, wetland: t6, water surface: t7, construction land: t8, and wasteland: t9.

(3) Variables and codes of the three industries (Unit: 10k yuan)

Primary industry: d1, secondary industry: d2, tertiary industry: d3.

2.4 Selection of constraint conditions

Condition of constraint is the limiting factor

when solving the objective function. Based on the actual situation in the Sanjiang Plain and planning reports such as the Heilongjiang Grain Production Capacity Planning, to determine constraint conditions of the model in terms of the natural resources, economic development, social stability, and ecological protection.

2.4.1 Water quantity constraint

(1) Available water resources constraint: The total water consumption of all departments throughout the Sanjiang Plain should not exceed the total available water resources, which can be expressed as:

$$\sum_{i=1}^{7} S_i \leqslant \text{dbs+dxs} \quad (1)$$

(2) Surface water (groundwater) constraint: Due to the over-exploitation of groundwater in the Sanjiang Plain, surface water should be used first in order to protect groundwater resources. Therefore we set groundwater precedence constraints: First use the surface water (including transferred water) to reduce groundwater resources exploitation.

$$\text{Dbs}_{\min} \leqslant \text{dbs} \leqslant \text{dbs}_{\max} \quad (2)$$

in which: $\text{dbs}_{\min}$ is the minimum consumption of surface water, and $\text{dbs}_{\max}$ is the maximum consumption of surface water.

$$\text{dxs} \leqslant \text{dxs}_{\max} \quad (3)$$

in which: $\text{dxs}_{\max}$ is the maximum consumption of surface water.

(3) Transit water constraint: According to the relevant planning, determine the upper and lower limits of transit water consumption,

$$\text{gjs}_{\min} \leqslant \text{gjs} \leqslant \text{gjs}_{\max} \quad (4)$$

in which: $\text{gjs}_{\min}$ is the minimum consumption of transit water, and $\text{gjs}_{\max}$ is the maximum consumption of transit water. Transit water should be used first compared with groundwater.

(4) Water constraint of consumption departments (units): According to the policy, planning or actual situation, the respective water consumption departments (units) have corresponding minimum and maximum limits of water consumption, which can be expressed as:

$$\text{si}_{\min} \leqslant \text{si} \leqslant \text{si}_{\max}, \ \text{i} \in (1,5) \quad (5)$$

where: $\text{si}_{\min}$ is the minimum water consumption; $\text{si}_{\max}$ is the maximum water consumption.

in which: s1 is the urban domestic water consumption, s2 is the rural domestic water consumption, s3 is the agricultural water consumption, s4 is the industrial water consumption and s5 is the water consumption of the tertiary industry.

(5) Ecological water demand constraint: Based on the basic idea of maintaining and playing the existing ecosystem functions and on the premise of not causing degradation of ecological functions, ecological water demand constrain refers to the amount of water required by ecosystem of the Sanjiang Plain. Due to the different water flow conditions in different years, ecological water demand changes accordingly.

$$\begin{aligned} \text{s6} &\geqslant \text{s6}_{\min} \\ \text{s7} &\geqslant \text{s7}_{\min} \end{aligned} \quad (6)$$

in which: $\text{s6}_{\min}$ is the minimum water consumption of urban ecosystem, and $\text{s7}_{\min}$ is the minimum water consumption of wetland ecosystem.

2.4.2 Land area constraint

(1) The total land area constraint: The sum of areas of all types of land use equals to the total land area, namely:

$$\sum_{i=1}^{7} \text{t i} = \text{t (total)} \quad (7)$$

in which: t total refers to total land area, t1 refers to dry land, t2 refers to paddy (high-yield), t3 refers to paddy (low and mid-yield), t4 refers to woodland, t5 refers to grassland, t6 refers to wetlands, t7 refers to water surface, t8 refers to construction land and t9 refers to wasteland.

(2) Minimum and maximum limits on all types of land area: The coverage of dry land, construction land, forest and grassland, wetland, *etc.* have minimum and maximum limits, namely:

$$\text{ti}_{\min} \leqslant (\text{t1, t4, t5, t6}) \leqslant \text{ti}_{\max}, \ \text{i=1} \quad (8)$$

in which: $\text{ti}_{\min}$, $\text{ti}_{\max}$ refer to minimum and maximum area of each land type respectively.

(3) Rice planting area constraint: According to the corresponding planning and policy, to improve food production and optimize planting structure, rice planting area should have its maximum and minimum limits, namely:

$$\text{ti}_{\min} \leqslant \text{ti} \leqslant \text{ti}_{\max}, \ \text{i} \in (2,3) \quad (9)$$

2.4.3 Per capita food production or employ-

ment rate constraint

For major grain production areas, the grain yield in the whole area should be no less than a certain level of value.

$$(ds1\times t2+ds2\times t3+dh1\times t1)\geqslant LSCL_{min} \quad (10)$$

in which: ds1 means per unit area yield of high-yield rice;

ds2 means the average per unit area yield of low and mid-yield rice;

dh1 means per unit area yield of upland;

$LSCL_{min}$ means the food production minimum limit.

2.4.4 Regional industry value-added constraint

According to the regional development planning, in different planned years, the added value of the primary industry, the secondary industry and the tertiary industry has its own corresponding minimum limits.

$$d1\geqslant D1_{min} \quad (11)$$

in which: ds1 is the output value of the primary industry;

$D1_{min}$–value-added limit of the primary industry.

$$s4\times cg\geqslant D2_{min} \quad (12)$$

in which: $D2_{min}$ is the value-added limit of the secondary industry;

cg is the contribution to the added value of the tertiary industry with the per unit of water investment.

$$sc5\times c3\geqslant D3_{min} \quad (13)$$

in which: c3 means the contribution of per unit of water to the added value of the tertiary industry;

$D3_{min}$ means the value-added limit of the secondary industry.

In order to ensure the smooth development of regional economy, we also took into account that the proportion of added value of tertiary industry should fluctuate within a certain range. By doing so, water resources allocated to the secondary and tertiary industries that have higher added value per unit of water will be limited effectively, which can be expressed as:

$$di/(d1+d2+d3)\in(lj, lk) \quad (14)$$

in which: di -added value of the i industry, i = 1, 2, 3; li, lk-the upper and lower limits of the proportion of added value of i industry in the total added value of the three industries.

2.4.5 Ecological environment constraint–the lower limit of ecological service value

Ecosystem service refers to all ecosystem products and service that do contribution to human beings and their living conditions. In this allocation, the lower limit is set as the ecosystem service value of nine land use types in 2010. The ecosystem service value at different levels of the Sanjiang Plain allocation should be higher than the status quo in 2010.

$$ESV\geqslant ESV_{min} \quad (15)$$

$$ESV=\sum_1^n t_i * v_i \quad (16)$$

in which: ESV is the total value of ecosystem services of the Sanjiang Plain;

ESV_{min} is the lower limit of the ecosystem service value of the Sanjiang Plain;

v_i is the contribution of the unit area of the *i* type of land use to ecosystem service value.

2.4.6 Non-negative constraint

All decision variables in the model are non-negative numbers, so that variables should be meaningful, which can be expressed as:

$$X_i\geqslant 0 \ (i=1, 2, 4\ldots, 22) \quad (17)$$

2.5 Determination of objective function

In order to allocate the land and water resources of the Sanjiang Plain more reasonably and scientifically, the objective function of the model is set from the aspects of economy, society and ecology.

(1) Economic goal

Choose the maximum number of total added value of the three industries (primary industry, secondary industry and tertiary industry) of the Sanjiang Plain and set it as the economic goal of the model, which can be expressed as:

$$Max_{economy}=d1+d2+d3 \quad (18)$$

(2) Social goal

Set the maximum food production of the Sanjiang Plain as the social goal of the model, which can be expressed as:

$$Max_{society}=1\times 37.50\times 0.1+t1\times 15.00\times 0.9+t2\times 75.00+t3\times 37.50\times 0.5+t3\times 18.00\times 0.5 \quad (19)$$

(3) Ecological goal

Set the maximum ecosystem service value of the Sanjiang Plain as the ecological goal of the model, which can be expressed as:

$$Max_{ecology}= t1\times80.70+115.42\times t2+115.42\times t3+155.12\times t4+71.10\times t5+301.58\times t6+234.47\times t7 \quad (20)$$

3 Global optimal solution

The main idea of the overall optimal solution is to break down the original problem into a series of convex programming (theoretically, the partial optimal solution of the convex programming is the overall optimal one), which should then be controlled through the branch and bound management program.

The search rule of the overall optimization is as follows: If the system has m independent decision variables, use $k>m+1$ vertexes to form a convex polygon (when $k<5$, could use $k=2m$; generally $k>m+2$). Decide the search directions based on the advantages and disadvantages of the objective function of the overall optimized solution vertexes. As the convex polygon can shrink and expand in all directions with high flexibility, the calculation is more flexible and thus the application scope is broader. Specific steps are as follows:

3.1 Generation of the initial convex polygon

The first step of the overall optimized solution is to generate an initial convex polygon in a feasible region, that is, each vertex should satisfy the given constraints,

$$a_i \leqslant u_i \leqslant b \ (i=1, ..., m) \quad (21)$$

$$A_j \leqslant g_j(U) \leqslant B_j \ \ (j=1, ..., k) \quad (22)$$

All vertexes are generated randomly by means of random numbers, which means that $r_{j,i}$ ($0 \leqslant r_{j,i} \leqslant 1$, i =1, …, m; j=1, …, k), a random number, will be generated by computer, and then $u_{j,i}$ can be obtained, which means the component i of the vertex j. To check U_j using implicit inequality, if the result is not satisfied, move U_j towards the center of gravity of the shape formed by points that satisfy the requirement, define:

$$U_j' = (1-b)U_j + bU_M, 0 < b < 1 \quad (23)$$

$$U_M = \frac{1}{M}\sum_{k=1}^{M} U_k \quad (24)$$

where, U_k (k=1, ..., m) is the vertex that satisfies all conditions of constraint, and U_M is the center of gravity. Repeat the above step until obtain all k vertexes. The aforesaid method is the most convenient one, yet its rate of convergence is slow. It can meet the requirement for the sustainable development of water resources in the river basin, making it an applicable method to generate the initial convex polygon.

3.2 Identification of local singularity

Calculate and compare the objective functions of the system with k vertexes, and then find out the "worst" U_W and the "best" U_b, namely,

$$F(r,U_w) = \max_j F(r,U_j) \quad (25)$$

$$F(r,U_b) = \min_j F(r,U_j) \quad (26)$$

$$\frac{1}{k}\sum_{j=1}^{k}[F(r,U_b)-F(r,U_j)]^2 \leq e \quad (27)$$

If the relation of (27) is satisfied, stop iteration for U_b will be the best solution that meets the requirement for accuracy; if such relation cannot be satisfied, go to next step. In the inequation (27), e is the criterion for convergency.

3.3 Discovery of the reflecting point

Calculate U_c, the center of gravity of the shape formed by the vertexes excluding points of U_w.

$$U_c = \frac{1}{k-1}\sum_{\substack{i=1 \\ i\neq w}}^{k} U_i \quad (28)$$

Check U_c to find out whether it can satisfy the condition of constraint or not.

If U_c satisfies all conditions of constraint, calculate the new point U_r through multiplying n times of the reflection of the worst point to the center of gravity, as "good" points are always at the opposite direction of "bad" points.

$$U_r = U_c + n(U_c - U_w) \quad (29)$$

The equation refers to the distance from the new point to the center of gravity, and the recommended value of BOX should be between 1.0–1.5.

If U_c cannot satisfy the conditions of restraint, two adjustment approaches can be applied: The first approach is to minimize the convex polygon with U_b and U_c as the limit values, if $u_{i,c} > u_{i,b}$, define ai=ui, b, $a_i=u_{i,b}$, $b_i=u_{i,c}$ (i=1,..., m), and then turn to the first step; the other approach is to stop the calculation and select the best point directly as the optimal result.

3.4 Check of the feasibility of the reflecting point

If U_r satisfies the conditions of restraint, go to the next step;

If U_r fails to satisfy the constraint of the inequation and $u_{i,r}<a_i$ or $u_{i,r}>b_j$, change to other points on the corresponding boundaries, define $u_{i,r}=a_i$ or $u_{i,r}=b_j$, and continue the calculation;

If U_r cannot satisfy the constraint of implicit inequation, apply $n=1/2n$ until such condition of constraint is met, and then go to the next step.

3.5 Calculation of optimal solution

Compare the objective function values of the reflecting point and the worst point, and calculate $F(r, U_r)$.

If $F(r, U_r)< F(r, U_w)$, replace U_M with U_r to form a new convex polygon and then go to the second step;

If $F(r, U_r)>F(r, U_w)$, calculate with $n=1/2n$ until the reflecting point becomes better than the worst point, or until $n<z\ (z>0)$, if the reflecting point cannot be further improved, stop the calculation and select the optimal result directly.

4 Result of optimized allocation

Resolution of the allocation model is carried out mainly from the following three levels to determine the allocation plan of water and land resources in the Sanjiang Plain: (1) The overall water resources allocation plan is based on a reasonable allocation proportion among the three industries, targeted at maximum economic benefits; (2) According to the requirement on the largest output, to achieve the maximum social benefit after taking into account the optimal use of local water and transit water, the surface water and groundwater, as well as coordinating urban and rural domestic, industry, agriculture, ecology and other water consumption; and (3) To maximize the ecological, social and economic goals to achieve a win-win outcome of grain production and wetland protection in the Sanjiang Plain.

4.1 Water supply allocation

On the premise of strengthening water-saving mode and implementing the recommended plan for the balance of supply and demands, water supply allocation refers to the reasonable deployment of surface water, groundwater, local water, transit water and other water sources based on the water resources and development levels in the Sanjiang Plain, so as to guarantee the sustainable development of the Sanjiang Plain.

In 2020, the Sanjiang Plain will be allocated with off-stream water supply of 13.292×10^9 m^3, including 8.63×10^9 m^3 is 50%-type annual surface water and 4.662×10^9 m^3 is groundwater. As for the amount of surface water supply, supply form the transit water for water is 4.49×10^9 m^3, and the supply of local surface water is 4.14×10^9 m^3. Specific results are shown in Table 1.

Table 1 Available water supply in the Sanjiang Plain (Unit: 10^4 m^3)

Region	Type of the year	Surface water	Groundwater	Transit water	Total water supply
Jiamusi	50%	174 281	206 100	312 900	693 281
	75%	95 500	168 700	336 600	600 800
	2010	162 300	263 450	23 700	449 450
Hegang	50%	126 120	147 800	87 900	361 820
	75%	79 700	110 800	87 900	278 400
	2010	26 100	37 100	0	63 200
Shuangyashan	50%	113 645	112 300	48 200	274 145
	75%	65 100	112 300	48 200	225 600
	2010	107 400	111 750	0	219 150
Sanjiang Plain	50%	414 046	466 200	449 000	1 329 246
	75%	240 300	391 800	472 700	1 104 800
	2010	295 800	412 300	23 700	731 800

The Sanjiang Plain water supply has changed greatly compared with 2010, which can be mainly seen from the following aspects: Small increase in the amount of surface water exploitation, significant groundwater reduction, and dramatic increase in transit water supply. The main reason

for such change is that the paddy fields in northern China extended towards the north, resulting in an increase of paddy cultivation and groundwater resource development within the latitude 47°–48°N. Besides, to alleviate the shortage of local water resources, a new transit water diversion project has been carried out. According to Table 1, in 2020 Jiamusi will witness a slight increase of surface water compared with the status quo, the use of groundwater will be reduced, and the transit water exploitation will be increased substantially; Hegang reduces its use of surface water and groundwater, and increases the transit water exploitation. As Shuangyashan has serious water shortage problems, it slightly increases the use of surface water and groundwater, and will start to use the transit water. In general, as for the water resources allocation of the Sanjiang Plain in 2020 compared with the status quo, the development of surface water will be reduced, with the expansion of paddy towards the north, the annual adjustment function and utilization of the underground reservoir in the Sanjiang Plain will be strengthened; transit water use will be increased thanks to two rivers and one lake project, which helps enhance utilization level of transit water in the area greatly (the amount of water supply has been proved).

4.2 Adjustment of land use structure

The Sanjiang Plain land resource allocation plan has significant changes in different types of year compared with the current situation. Details are shown in Table 2:

Table 2 Land resources allocation plan of the Sanjiang Plain (Unit: km^2)

Region	Type of the year	Dry land	Paddy	Forest	Grass-land	Wet-lands	Water body	Construc-tion land	Waste-land	Total area
Jiamusi	50%	12809	10620	4404	128	3069	950	754	0	32734
	75%	11230	12199	4404	128	3069	950	754	0	32734
	2010	14544	9346	4404	128	2593	950	754	16	32734
Hegang	50%	1410	5574	5967	38	929	239	489	0	14646
	75%	2916	4068	5967	38	929	239	489	0	14646
	2010	5032	2300	5967	38	580	239	489	0	14646
Shuang-yashan	50%	8487	3588	7912	43	1342	168	489	0	22029
	75%	8396	3679	7912	43	1342	168	489	0	22029
	2010	9485	2872	7912	43	1100	167	449	0	22029
Study area	50%	22706	19782	18283	209	5340	1356	1732	0	69408
	75%	22542	19946	18283	209	5340	1356	1732	0	69408
	2010	29061	14518	18283	209	4273	1356	1692	16	69408

Table 3 Allocation plan and objective function of three industries of the Sanjiang Plain

Region	Type of the year	Output (10 k yuan)				Ratio (%)			Grain yield (100×10^6 kg)	Ecological services value
		Primary industry	Secondary industry	Tertiary industry	Gross output	Primary industry	Secondary industry	Tertiary industry		
Jiamusi	50%	243	141	258	642	38	22	40	91	410
	75%	220	141	258	619	36	23	42	82	415
	2010	145	92	195	433	34	21	45	48	395
Hegang	50%	70	163	130	363	19	45	36	25	202
	75%	62	163	78	303	20	54	26	23	197
	2010	50	94	59	202	24	46	29	7	183
Shuangyashan	50%	83	241	112	436	19	55	26	37	256
	75%	83	241	112	436	19	55	26	37	257
	2010	92	130	77	298	31	43	26	19	269
Study area	50%	396	545	499	1440	27	38	35	153	868
	75%	365	545	447	1357	27	40	33	142	869
	2010	286	316	331	933	31	34	35	74	847

As can be seen from Table 2, compared with 2010, the paddy field area in the Sanjiang Plain has increased steadily; dry land area has declined year after year due to poor profits; part of the dry land has been transformed into paddy, thus increasing the paddy field area, and part of the dry land has been changed to wetland, and thus the wetland area has grown slightly; while part of such land has turned to wasteland due to lack of water, leading to the expansion of wasteland area; specific implementation should be carried out after fully analyzing the input-output ratio of arable land so

as to guide farmers in farming.

4.3 Three industries and their objective functions

According to the calculation of the allocation model, if water and land resources are allocated in accordance with the optimal solution, the objective function value of the three industries' output value is 13.72×10^6 yuan in the Sanjiang Plain, about 4.39×10^6 yuan higher than the current value; production will reach 16.5×10^9 kilograms, 9.1×10^9 yuan higher than the current value; the value of ecosystem services will decrease by 56.9×10^9 yuan, which is the cost for safety production of crops.

As can be seen from Table 3, compared with 2010, the structure of three industries in the Sanjiang Plain has been changed slightly, especially for the 75%-type years, the proportion of the secondary industry increased considerably, so the food production and regional GDP need further coordination; the overall proportion of the tertiary industry of the Sanjiang Plain changed slightly, and is relatively stable.

In Jiamusi, agriculture has the largest proportion, followed by the tertiary industry, so Jiamusi City should focus on developing agriculture as well as tourism and other tertiary industries; in Shuangyashan the second industry accounts for the largest part, so it should create industry chain of mining products deep processing; in Hegang industry and agriculture should develop in an equal proportion.

5 Conclusions

Based on the analysis and evaluation of ecological and economic situation in terms of water and land resources, this study established an ecological and economic allocation model for land and water resources, which including 3 objective functions, 6 types of constraints, 22 decision variables, determined the model parameters and proposed the optimal model resolution method. In addition, a sub-module that controls system platform was built based on Lingo10.0. The study was carried out in the Sanjiang Plain, and the model was solved by predicting the water resources and its socio-economic development, as well as setting different scenarios. In this way we gained a water and land resources allocation plan for 50%-level and 75%-level.

This study has provided the reference for the sustainable use and management of the water and land resources of the study area through proposing an ecological and economic allocation plan for land and water resources. After the implementation of the proposed water and land resources allocation plan for 50%-level and 75%-level year in 2020, it is expected that significant social, economic and ecological benefits will be generated.

(1) Economic benefits

After the implementation of the plan, under the premises of securing water supply for domestic, production and ecosystem required for the sustainable development of national economy in the region, the average annual growth rate of GDP in the application region from 2010 to 2020 will reach 2.1%, and by 2020 economic output will reach 144×10^9 yuan.

(2) Social benefits

Guarantee food security through adjusting the agricultural structure and developing water-saving irrigation. After the implementation of the plan, in 2020 the irrigation area will reach 2.21×10^6 hm^2. Combined with reasonable allocation plan of water resources, not only the water supply conditions of the existing irrigation area will be improved, but also the water needs for new irrigation area will be basically guaranteed. The water consumption guarantee system for food security will be established gradually, and thus the water consumption generated by food security demands will be better guaranteed.

(3) Ecological benefits

To carry out ecological protection work through focusing on wetland restoration and protection. After the implementation of the plan, the area of the wetlands will be increased from 4 273 km^2 in 2010 to 5 340 km^2 in 2020.

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