Comprehensive Evaluation of Regional Agricultural Water and Land Resources Carrying Capacity Based on DPSIR Concept Framework and PP Model

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Abstract. Aiming at the problems existing in the current use of agricultural water and land resources in China and in order to realize sustainable use of the two resources, we established an indicator system for comprehensive evaluation of agricultural water and land resources carrying capacity based on the Driving forces-Pressures-States-Impacts-Responses (DPSIR) concept framework. Then we took Sanjiang Plain as study area (including 6 cities and 1 county) and used projection pursuit (PP) model to evaluate regional agricultural water and land resources carrying capacity. The evaluation results indicated that seven indicators, including the arable wasteland rate, water resources utilization rate, urbanization rate, chemical fertilizer application in farmland per unit area, farmland irrigation rate, production GDP per unit water consumption and agricultural land output rate, were the key factors influencing agricultural water and land resources carrying capacity in Sanjiang Plain. Jiamusi, the main agricultural region of Sanjiang Plain, has the lowest carrying capacity of agricultural water and land resources. However, Muling has the highest carrying capacity. The evaluation results could provide scientific guidance for regional agricultural water and land resources sustainable use.

Keywords: DPSIR, Projection pursuit, Genetic algorithm, Agricultural water and land resources, Carrying capacity evaluation, Sanjiang Plain

1 Introduction

Agricultural water and land resources are the basis of the people's livelihood and the development. China is a big agricultural country, and along with the speediness of the progress of industrialization and urbanization, the trend that the agricultural water and land resources are misappropriated can not be changed. Misappropriation and deficiency of agricultural water and land resources not only induce destruction of regional structure and attenuation of production, ecology and life function of the two resources, but also directly threaten the sustainable carrying capacity of agricultural water and land resources in China and the sustainable and security production of national food [1] and [2]. Sanjiang Plain has flat terrain, fertile soil, appropriate climate and abundant water resources, which is a good natural condition for agricultural development. After years of exploitation and construction, Sanjiang Plain has become an important grain production base of China and played an important role in guaranteeing national food security [3]. However, under the interference of high strength mankind's activity, the quantity, quality, spatial matching status and carrying capacity of water and land resources in Sanjiang Plain have obviously changed. In the study, we established the Driving forces-Pressures-States-Impacts-Responses (DPSIR) concept framework of agricultural of water and land resources system and used projection pursuit (PP) model to assessment their carrying capacity comprehensively. At last, we found the current status and influencing factors of water and land resources carrying capacity of Sanjiang Plain and expected the results and conclusions could provide scientific guidance for further exploitation and optimal allocation of regional agricultural water and land resources.

2 Methods

2.1 DPSIR concept framework

Establishing a concept framework for carrying capacity evaluation of agricultural water and land resources can provide specific research thoughts, principles, approaches and frameworks for researchers; can help them to choose corresponding elements and indicators and to organize data or information; can guarantee important elements and information not to be ignored; and can analyze and solve the problems to be researched [4]. After years of researches and practices, scholars proposed a lot of framework models for agricultural water and land resources carrying capacity evaluation, hereinto, the Driving Forces-Pressures-States-Impacts-Responses (DPSIR) concept framework is the most widely used one.

For the purpose of comprehensively analyzing and describing environmental problem and its relation with social development, the United Nations proposed and developed the DPSIR model by synthesizing the advantages of the PSR model and the DSR model in 1993. The DPSIR model, considering the interaction between human and environment system from the standpoint of system analysis, is a concept framework of evaluation indicator system. It was widely used in environment system and also in the researches of resource, population, environment and agriculture developments.

The components of DPSIR concept framework are Driving Forces, Pressures, States, Impacts and Responses. Each component stands for a type of indicator and each type of indicator includes a number of indicators. The five components of DPSIR concept framework establishing the agricultural water and land resources system can be described as follows [5]:

(1) Driving Forces describe the developments of society, economy and population and the corresponding changes of life-style, consumption and production form of human beings. In the evaluation of agricultural water and land resources carrying capacity, Driving Forces are the reasons causing the changes of agricultural water and land resources system.

(2) Pressure indicators are the pressures that directly exert on agricultural water and land resources system and make the system develop and change after Driving Forces effect. The similarity of Driving Forces and Pressures is that they are both the external force making the system changes, while the difference between the two components is that the action mode of Driving Forces on the system developments and changes is implicit and that of Pressures is explicit.

(3) States of agricultural water and land resources are the realistic performances of the system under various kinds of pressures and the results of joint action of Driving Force and Pressure.

(4) Impact indicators are the final effects describing the state changes of agricultural water and land resources system.

(5) Responses are the management measures used to exploit and utilize agricultural water and land resources system.

2.2 Projection pursuit model

Projection pursuit is a statistical method used to analyze and process nonlinear and nonnormal high dimensional data. For the purpose of analyzing high dimensional data, the method pursuits the projection that reflects the structure and characteristics of the data by projecting high dimensional data to low dimensional subspace [6]. The steps of modeling of projection pursuit (PP) model for agricultural water and land resources carrying capacity are as follows [7]:

Step 1: Normalizing the evaluation indicators of each sample

Set the classification criterion sample set of regional agricultural water and land resources carrying capacity as $\{x^*(i,j) \mid i=1\sim n, j=1\sim p\}$, where $x^*(i,j)$ is the indicator j value of sample i, n the number of samples and p the number of indicators. In order to eliminate the dimension influence and unify the variable scope of each indicator value, we can adopt the following formulas to normalize the extreme value:

$$x(i,j)=\begin{cases}\dfrac{x^*(i,j)}{x_{\max}(j)} & \text{in case the bigger the indicator the better}\\[2ex] \dfrac{x_{\min}(j)}{x^*(i,j)} & \text{in case the smaller the indicator the better}\end{cases} \quad (1)$$

where $x_{\max}(j)$ and $x_{\min}(j)$ stand for the maximum and the minimum value of indicator j, respectively, and $x(i,j)$ stands for the array of normalized indicator characteristic value in the classification criterion sample set. In the study, the number of samples for evaluation n is 8 and the number of evaluation indicator p is 17.

Step 2: Constructing the projection indicator function $Q(a)$

Projection pursuit model is to integrate p-dimensional data, $\{x(i,j) \mid j=1\sim p\}$, into one-dimension projection value $z(i)$:

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

based on projection direction $a=\{a(1),a(2),a(3),\cdots,a(p)\}$, where a stands for unit length vector.

We then make a classification in accordance with one-dimension dispersion pattern of $\{z(i)\,|\,i=1\sim n\}$. A good classification for the method requires the local projection dots as close as possible and the integral projection dot groups as dispersive. Namely, the standard deviation and partial density values of multiple data interspersing among one-dimension space should be maximized at the same time. Thus, the projection indicator function can be expressed as follows:

$$Q(a)=S_z D_z \tag{3}$$

where S_z is the standard deviation of $z(i)$ and D_z the partial density of $z(i)$. Then we get

$$S_z=\sqrt{\frac{\sum_{i=1}^{n}(z(i)-E(z))^2}{n-1}} \tag{4}$$

$$D_z=\sum_{i=1}^{n}\sum_{j=1}^{n}(R-r(i,j))\cdot u(R-r(i,j)) \tag{5}$$

where $E(z)$ is the average value of series $\{z(i)\,|\,i=1\sim n\}$, R is the window radius of partial density, which can be settled by test, but is assumed to equal $0.1S_z$ in normal practice, $r(i,j)$ is the distance between the samples, $r(i,j)=|z(i)-z(j)|$, and $u(R-r(i,j))$ is a unit step function. Let $t=R-r(i,j)$, then $u(t)=1$ if $t\geq 0$ and $u(t)=0$ if $t<0$.

Step 3: Optimizing the projection indicator function

We can calculate the maximum value of $Q(a)$ to estimate the best project direction with restricted condition

$$\sum_{j=1}^{p}a^2(j)=1 \tag{6}$$

It is a complex non-linearity optimization, in which $\{a(j)\,|\,j=1\sim p\}$ is taken as the optimized variable. Therefore, it is quite difficult to make calculations with the traditional method. We now may adopt real coded accelerating genetic algorithm (RAGA). The modeling steps of RAGA can be found in reference [6].

Step 4: Comprehensive evaluation of agricultural water and land resources carrying capacity

We put the best projection direction $a*$ into Equation 2, and then we obtain the best projection value $z_s^*(i)$ of the samples for evaluation, namely, the comprehensive evaluation values of agricultural water and land resources carrying capacity.

3 Results and analysis

3.1 Establishing DPSIR concept framework

On the basis of the choosing principles of indicators and the establishing theory of DPSIR concept framework and the characteristics of regional socioeconomic developments, a DPSIR concept framework for agricultural water and land resources carrying capacity evaluation in Sanjiang Plain was established and showed in Table 1. The framework was comprised of five influencing factors (Driving Forces, Pressures, States, Impacts and Responses) and each factor included a number of indicators. Then it formed a multilevel and closely associated evaluation indicator system. The specific indicators are as follows:

(1) Driving Forces include GDP growth rate (x_1), population growth rate (x_2) and urbanization rate (x_3).

(2) Pressures include population density (x_4), reclaim rate (x_5) and agricultural water rate (x_6).

(3) States include agricultural land output rate (x_7), water resources utilization rate (x_8), water resource quantity per capita (x_9), farmland irrigation rate (x_{10}), grain yield per unit area (x_{11}) and chemical fertilizer application in farmland per unit area (x_{12}).

(4) Impacts include farmland area per capita (x_{13}), production GDP per unit water consumption (x_{14}) and arable wasteland rate (x_{15}).

(5) Responses include percentage of forest cover (x_{16}) and total motive power of farm mechanization per unit area farmland (x_{17}).

Table 1. DPSIR concept framework for agricultural water and land resources carrying capacity evaluation

Factor	Indicator	Jixi	Hegang	Shuang-yashan	Jiamusi	Qitaihe	Muling	Yilan	Sanjiang Plain	a^*
Driving Forces	x_1 (%)	12.3	12.3	15.2	15.9	26.1	13.4	17.6	16.11	0.158
	x_2 (‰)	3.67	0.67	0.38	4.66	7.71	2.99	8.32	3.58	0.017
	x_3 (%)	62.89	80.62	62.26	49.26	56.43	41.72	32.01	58.14	0.359
Pressures	x_4 (person/km^2)	85	75	68	77	145	50	88	79	0.142
	x_5 (%)	31.93	29.48	36.63	41.65	31.32	18.73	42.45	35.08	0.071
	x_6 (%)	93.4	96.4	96.3	98.8	72.9	78.6	98.5	96.1	0.075
States	x_7 (10^4RMB/hm^2)	1.56	1.26	1.42	1.38	0.99	1.69	0.7	1.36	0.221
	x_8 (%)	70.6	32.88	53	82.17	15.69	5.53	28.95	55.03	0.464
	x_9 (m^3 per capita)	2356	3292	2456	2081	927	3969	2647	2337	0.048
	x_{10} (%)	50.62	43.81	35.11	45.2	9.8	7.7	14.34	39.37	0.285
	x_{11} (kg/hm^2)	6643	6232	6249	6383	3779	2380	5270	6070	0.000

	x_{12} (kg/hm^2)	138.1	201.2	147	189.7	85.7	64.7	84.9	157.8	0.305
Impacts	x_{13} (hm^2 per capita)	0.38	0.4	0.54	0.54	0.22	0.37	0.48	0.44	0.155
	x_{14} (RMB/m^3)	9.95	15.6	13.28	9.26	142.69	89.17	16.82	13.13	0.260
	x_{15} (%)	16.45	11.4	11.75	20.2	8.34	2.41	5.14	14.17	0.531
Responses	x_{16} (%)	35.45	45.01	41.74	19.26	52.8	74.58	38.75	36.61	0.013
	x_{17} (kw/hm^2)	3.44	2.76	2.68	2.51	2.49	1.19	2.2	2.69	0.002

Note: The data in Table 1 comes from the reference [8].

3.2 Evaluating agricultural water and land resources carrying capacity

On the basis of PP theory, we structured the projection indicator function and optimized the best projection direction a^* by using RAGA which simulated the mechanisms of creature survival of the fittest and chromosome information exchange in colony inside. The programs were realized in MATLAB 7.0 software. In the optimization process of RAGA, we set the initial population size of parent n as 400, the crossover probability p_c as 0.8, the variation probability as p_m 0.8, the amount of the excellent individuals as 20, the parameter α as 0.05 and the maximum accelerating time as 20. Then we put the best projection directions a^* (shown in Table 1) into Equation 2 and obtained the projection values $z^*(i)$ of the samples for evaluation, namely the comprehensive evaluation values of the agricultural water and land resources carrying capacity in the study area.

After projection transformation and the beat projection directions determination, the projection values $z^*(i)$ of the agricultural water and land resources carrying capacity evaluation in the study area are 0.847 (Jixi), 0.847 (Hegang), 0.876 (Shuangyashan), 0.836 (Jiamusi), 1.489 (Qitaihe), 2.349 (Muling), 1.490 (Yilan) and 0.853 (Sanjiang Plain). The results show that the agricultural water and land resources carrying capacity of the whole Sanjiang Plain region is relatively low (0.853); Muling is relatively high (2.349); Qitaihe and Yilan are moderate (1.489~1.490); and Jixi, Hegang, Shuangyashan and Jiamusi are relatively low (0.836~0.876).

3.3 Influencing factor analysis of agricultural water and land resources carrying capacity

The purpose of agricultural water and land resources carrying capacity evaluation is assessing the current states of resources utilization and their capacities supporting society-ecology-environment system, what more important is finding the influencing factors of agricultural water and land resources carrying capacity in order to adjust the current utilization policies for agricultural resources exploitation.

In the comprehensive evaluation of agricultural water and land resources carrying capacity based on PP model, the best projection direction $a^*(j)$ quantitatively shows the influence degree of the j indicator on regional agricultural water and land resources carrying capacity. Namely, the bigger $a^*(j)$ is the higher the influence degree of the j indicator on it. According to Table 1, the sequence of influence degree of the indicators on agricultural water and land resources carrying capacity is arable wasteland rate> water resources utilization rate> urbanization rate> chemical fertilizer application in farmland per unit area> farmland irrigation rate> production GDP per unit water consumption> agricultural land output rate>the other indicators. The influence degree summation of the former seven indicators on agricultural water and land resources carrying capacity is 0.917. Thus, they can be considered as the key influence factors of regional agricultural water and land resources carrying capacity.

In the process of socioeconomic developments and utilization policy adjustments of agricultural water and land resources in Sanjiang Plain, the measures, enhancing the exploitation and utilization degree of agricultural water and land resources, controlling the urban development speed, reducing chemical fertilizer application and increasing farmland irrigation rate, are the key points that can enhance the carrying capacity of agricultural water and land resources and ensure resources sustainable utilization.

4 Conclusions

On the basis of the choosing principles of indicators and establishing theory of DPSIR concept framework and the characteristics of regional socioeconomic developments, a DPSIR concept framework for agricultural water and land resources carrying capacity evaluation was established. And the framework includes 5 influence factors and 17 indicators.

A comprehensive evaluation model for agricultural water and land resources carrying capacity based on RAGA-PP was constructed and used for the 6 cities and 1 county in the Sanjiang Plain region. The evaluation results indicated that the agricultural water and land resources carrying capacity of the whole Sanjiang Plain region is relatively low. Thus, a reasonable plan for the exploitation and utilization of agricultural water and land resources should be made on the basis of the regional characteristics.

According to the sequence of the influence degree of the indicators on agricultural water and land resources carrying capacity, arable wasteland rate, water resources utilization rate, urbanization rate, chemical fertilizer application in farmland per unit area, farmland irrigation rate, production GDP per unit water consumption and agricultural land output rate are the key factors influencing the agricultural water and land resources carrying capacity in Sanjiang Plain. In the future adjustment of agricultural water and land resources exploitation and utilization, improving the key factors is the core that can enhance the carrying capacity of agricultural water and land resources and ensure resources sustainable utilization.

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