Early warning evaluation and warning trend analysis of the resource and environment carrying capacity in Altay prefecture, Xinjiang

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1. Calculation of index weights by the entropy method

1）Calculate the weight of the jth index value of the ith evaluation scheme in the sum of the index values P_{ij}:

$$p_{ij} = \frac{x_{ij}}{\sum_1^n x_{ij}}$$

(S1)

2）Calculate the entropy value e_j of index x_{ij}:

$$e_j = -k\sum_{i=1}^{n} p_{ij} \ln(p_{ij})$$

(S2)

3）Calculate the difference coefficient h_j of index x_{ij}:

$$h_j = 1 - e_j$$

(S3)

4）Calculate the weight w_j of index x_{ij}:

$$W_j = \frac{h_j}{\sum_j^n h_j}$$

(S4)

2. Basic principle of BP neural network

BP neural network is a multilayer feedforward neural network with hidden layer based on the error back propagation algorithm. BP neural network consists of several neurons that form the input layer, hidden layer and output layer. The running process of the algorithm includes two stages, namely forward propagation and back propagation. The input samples are transmitted from the input layer to the output layer through the hidden layer. Each layer of neurons only affects the next layer of neurons in one direction, called forward propagation. Then, compare the error between the predicted and set output [1]. Suppose the error between the predicted output and the set output exceeds the accuracy range set by the BP neural network. In that case, the error is passed back from the output layer to the hidden layer. The linkage weights and thresholds of each neuron are adjusted layer by layer until the output sample error meets the network accuracy requirements, which is the backward propagation [2]. The main limitation of BP neural network model is its slow rate of convergence, easy to fall into local minimum and poor fault tolerance. The selection of corresponding parameters and the number of hidden layer neurons in the model often adopts the trial and error method, which has a certain degree of subjective blindness in practical application. BP neural network prediction requires an appropriate amount of data volume as the input layer, and relatively sufficient input samples can improve generalization ability. The model can continuously learn and train to extract data change patterns from existing complex data. However, excessive data samples can lead to overfitting and poor generalization ability. Other conditions that must be considered for correct operation are that the original data must be normalized. It is necessary to select appropriate input layer, output layer, and hidden layer neuron numbers based on the characteristics of the predicted object. It is also necessary to determine the appropriate neural network training function [1, 2].

3. Learning algorithms for BP neural networks

The standard BP neural network algorithm included two aspects: one was for the input signal, that was, forward propagation; On the other hand, for the error between the predicted value and the expected value, namely, backpropagation [3].

（1）Forward propagation process of the signal

The signal was input from the input layer, processed by the hidden layer, and then passed to the output layer.

（2）Back propagation process of the error

If the actual output of the output layer did not match the desired output, it entered the back propagation of error stage. The back propagation of error was actually to adjust the network parameters, namely weight value and threshold value, by calculating the total error between the output of all neurons in the output layer and the actual value. By finding the derivative of the error on the weight value or threshold value of each layer neuron, the direction and size of the parameter correction were further determined, and the corrected network was trained repeatedly, which was the learning and training process of the network. Until the output sample error met the neural network's accuracy requirements, the training was finished [3].

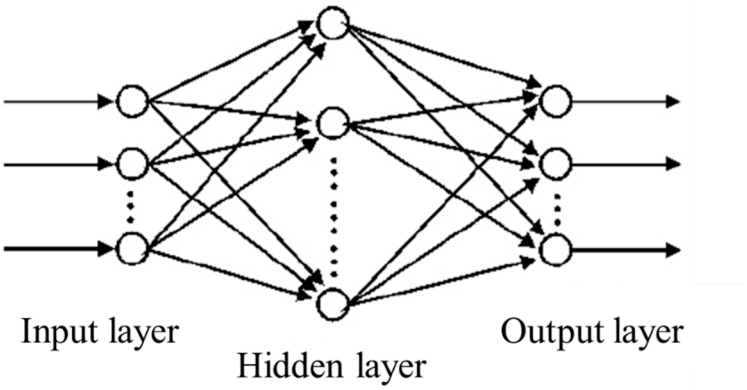

Figure S1 Structure of BP neural network model

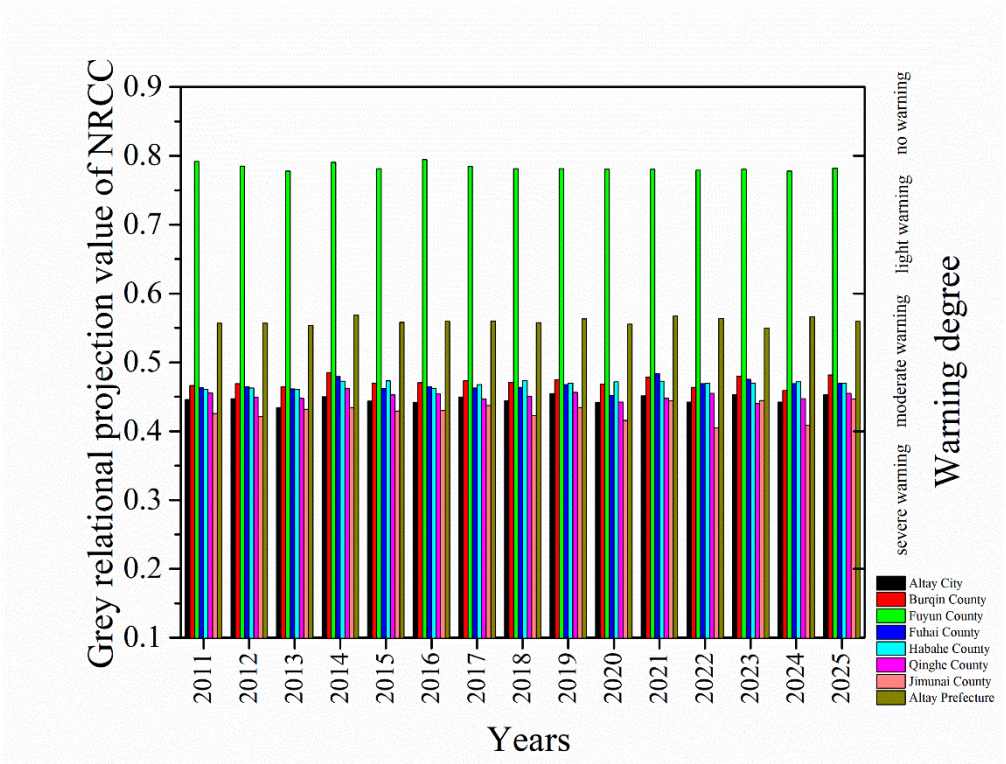

Figure S2 The histogram of natural resource carrying capacity risk in Altay Prefecture and counties and cities from 2011 to 2025.

Table S1 Comparison of fitting errors of BP neural network in Altay Prefecture, counties and cities

System / Region	Resource and environment carrying capacity	Natural resource carrying capacity	Eco-environment carrying capacity	Economic and social support
Altay City	0.0053	0.0008	0.0028	0.0069
Burqin County	0.0009	0.0057	0.0133	0.0206
Fuyun County	0.0028	0.0004	0.0070	0.0085
Fuhai County	0.0051	0.0041	0.0045	0.0092
Habahe County	0.0020	0.0017	0.0066	0.0041
Qinghe County	0.0021	0.0040	0.0341	0.0033
Jimunai County	0.0014	0.0049	0.0011	0.0239
Altay Prefecture	0.0009	0.0024	0.0036	0.0163

Table S2 Risk warning signal status of resource and environment carrying capacity of Altay Prefecture and counties and cities from 2011 to 2025

Region / Years	Altay City	Burqin County	Fuyun County	Fuhai County	Habahe County	Qinghe County	Jimunai County	Altay Prefecture
2011	▲	▲	●	▲	▲	▲	▲	▲
2012	▲	▲	●	▲	▲	▲	▲	▲
2013	▲	▲	●	▲	▲	▲	▲	▲
2014	▲	▲	●	▲	▲	▲	▲	▲
2015	▲	▲	●	▲	▲	▲	▲	▲
2016	▲	▲	●	▲	▲	▲	▲	▲
2017	▲	▲	●	▲	▲	▲	▲	▲
2018	▲	▲	●	▲	▲	▲	▲	▲
2019	▲	▲	●	▲	▲	▲	▲	▲
2020	▲	▲	●	▲	▲	▲	▲	▲
2021	▲	▲	●	▲	▲	▲	▲	▲
2022	▲	▲	●	▲	▲	▲	▲	▲
2023	▲	▲	●	▲	▲	▲	▲	▲
2024	▲	▲	●	▲	▲	▲	▲	▲
2025	▲	▲	●	▲	▲	▲	▲	▲

Notes：▲ represented yellow light，● represented blue light.

Table S3 Status of risk warning signal lights of natural resources carrying capacity in Altay from 2011 to 2025

Region / Years	Altay City	Burqin County	Fuyun County	Fuhai County	Habahe County	Qinghe County	Jimunai County	Altay Prefecture
2011	▲	▲	●	▲	▲	▲	▲	▲
2012	▲	▲	●	▲	▲	▲	▲	▲
2013	▲	▲	●	▲	▲	▲	▲	▲
2014	▲	▲	●	▲	▲	▲	▲	▲
2015	▲	▲	●	▲	▲	▲	▲	▲
2016	▲	▲	●	▲	▲	▲	▲	▲
2017	▲	▲	●	▲	▲	▲	▲	▲
2018	▲	▲	●	▲	▲	▲	▲	▲
2019	▲	▲	●	▲	▲	▲	▲	▲
2020	▲	▲	●	▲	▲	▲	▲	▲
2021	▲	▲	●	▲	▲	▲	▲	▲
2022	▲	▲	●	▲	▲	▲	▲	▲
2023	▲	▲	●	▲	▲	▲	▲	▲
2024	▲	▲	●	▲	▲	▲	▲	▲
2025	▲	▲	●	▲	▲	▲	▲	▲

Notes： ▲ represented yellow light， ● represented blue light.

Table S4 Status of risk warning signal lights of ecological environment carrying capacity in Altay region from 2011 to 2025

Region / Years	Altay City	Burqin County	Fuyun County	Fuhai County	Habahe County	Qinghe County	Jimunai County	Altay Prefecture
2011	▲	▲	▲	●	▲	▲	●	▲
2012	▲	▲	▲	●	▲	▲	●	▲
2013	▲	▲	▲	★	▲	▲	●	▲
2014	▲	▲	▲	★	▲	▲	●	▲
2015	▲	▲	▲	★	▲	▲	●	▲
2016	▲	▲	▲	★	▲	▲	●	▲
2017	▲	▲	▲	★	▲	▲	●	▲
2018	▲	▲	▲	★	▲	▲	●	▲
2019	▲	▲	▲	★	▲	▲	●	▲
2020	▲	▲	▲	★	▲	▲	●	▲
2021	▲	▲	▲	★	▲	▲	●	▲
2022	▲	▲	▲	★	▲	▲	●	▲
2023	▲	▲	▲	★	▲	▲	●	▲
2024	▲	▲	▲	★	▲	▲	●	▲
2025	▲	▲	▲	★	▲	▲	●	▲

Notes： ▲ represented yellow light, ● represented blue light, ★ represented green light.

Table S5 Status of early warning signals of economic and social support in Altay region from 2011 to 2025

Region / Years	Altay City	Burqin County	Fuyun County	Fuhai County	Habahe County	Qinghe County	Jimunai County	Altay Prefecture
2011	●	▲	▲	▲	★	▲	▲	▲
2012	●	▲	▲	▲	★	▲	▲	▲
2013	●	▲	▲	▲	★	▲	▲	▲
2014	●	▲	▲	▲	●	▲	▲	▲
2015	●	▲	▲	▲	●	▲	▲	▲
2016	★	▲	▲	▲	●	◆	▲	▲
2017	★	▲	▲	▲	●	▲	●	▲
2018	★	▲	▲	▲	●	▲	▲	▲
2019	★	▲	▲	▲	▲	▲	▲	▲
2020	★	▲	▲	▲	●	▲	▲	▲
2021	★	▲	▲	▲	●	▲	▲	▲
2022	★	▲	▲	▲	▲	▲	▲	▲
2023	★	▲	▲	▲	●	▲	▲	▲
2024	★	▲	▲	▲	●	◆	▲	▲
2025	★	●	▲	▲	▲	▲	▲	▲

Notes：◆represented orange light, ▲ represented yellow light, ● represented blue light, ★ represented green light.

Reference

[1] Sheng, X.; Zhang, H.; Su, C. Fenhe river water quality assessment based on bp neural network. Journal of Shanxi University (Natural Science Edition), 2013, 36, 301-307.

[2] Cao, R.X.; Zhang, K.X.; Zeng, W.H.; et al. Early warning research on water environment carrying capacity based on BP neural network -- taking the North Canal as an example. Journal of Environmental Science, 2021, 41, 2005-2017.

[3] Li, Y.K. Research, analysis, improvement and application of BP neural network. Anhui University of Science and Technology, 2012.