DOI:10.13476/j.cnki.nsbdqk.2020.0077
YAN J,PAN Z F,TAN J,et al. Assessment of water quality by firefly algorithm based on BP neural network model[J]. South-to-North Water Transfers and Water Science & Technology,2020,18(4):104-110. (in Chinese)

Assessment of water quality by firefly algorithm based on BP neural network model

YAN Jian,PAN Zhifu,TAN Jing,TIAN Han

(Lianyungang Urban Water Conservancy Project Management Department,Lianyungang 222003,China)

Abstract:Assessment of water quality by firefly algorithm based on BP neural network model (FA-BP model) is built. In this model,the evaluation index function is constructed by BP Artificial Neural Network Algorithm (BP model),and Firefly Algorithm (FA model) is introduced to optimize weight values and thresholds to find the optimal solution. Fuzzy Comprehensive Evaluation method,Grey Incidence Analysis Algorithm and FA-BP model will be applied to evaluate the water quality of the five main rivers in Lianyungang City including Longwei, Yudai, Dapu, Paidan,and Dongyan River. The results show that:the Fuzzy Comprehensive Evaluation method is difficult to use for slight pollution rivers with several slightly over standard indexes,it will be easy to ignore the impact of extreme indexes by Grey Incidence Analysis Algorithm. FA-BP model solves the shortcomings of the two methods. The evaluation results provide an important reference for the formulation of reasonable measures. It is a relatively comprehensive evaluation method and has a good application prospect in water quality evaluation.

Key words:firefly algorithm;BP neural network;surface water;assessment of water quality

Chinese Library Classification No. :X824 **Document Code**:A OSID:

In recent years,due to the lack of long-term management mechanism and the impact of human activities, rivers are polluted to varying degrees[1-2], water environment system is damaged, water quality continues to deteriorate, and even black and smelly water bodies appear[3-5]. In order to improve the water environment, the black and smelly water body is renovated in many cities across China. Great process has been made in remediation technologies related to river water pollution. Water quality assessment becomes an essential work for water environment management and protection,as well as pollution control[6-7]. Comprehensive assessment of water quality would help understand current situation of water pollution of rivers,and is helpful for water environment improvement and water ecology protection.

There are many methods for evaluating surface water quality[8-10],which are mainly divided into three categories. Firstly, the index evaluation method was used, which is the ratio of measured data of each index to the evaluation standard as

Received:2020-03-24 **Revised**:2020-04-30 **Online publishing**:2020-05-09
Online publishing address:http://kns.cnki.net/kcms/detail/13.1430.tv.20200508.1907.004.html
Funds:Research Project of Lianyungang Association for Science and Technology (Lkxyb1907);Research Project of "333 Project" of Jiangsu Province (BRA2019245);Research Project of "521" Project of Lianyungang City (LYG52105-2018090)
Author brief:YAN Jian (1978-),male,Jiangsu Province,senior engineer,mainly engaged in water conservancy project management. E-mail:654434268@qq.com
Corresponding author:TAN Jing (1989-),male,Jiangsu Province,doctor,mainly engaged in water conservancy project management. E-mail:tanjing2006@126.com

sub-index. And then comprehensive index will be obtained by calculation. This method includes the Single Factor Index Evaluation Method[11] and the Comprehensive Index Evaluation Method[12]. Secondly, an uncertain evaluation method was used. There are many uncertain factors in water environment, which belongs to a random and fuzzy system. Uncertain evaluation methods can avoid the influence of uncertainty on water environment such as Fuzzy Comprehensive Evaluation, Grey Incidence Analysis Algorithm[13-15]. Thirdly, with the rapid development of computer technology, intelligence algorithm applied to water quality evaluation has been widely accepted, including Artificial Neural Network[16], Geographic Information System, and Projection Pursuit Model[17-18]. Work efficiency has been improved by Intelligence Algorithm. However, it is less than enough to use a single intelligence algorithm. It also has some shortcomings. For example, the artificial neural network has many parameters and is easy to fall into local optimum. The genetic algorithm often falls into local optimum[19-20].

According to the bulletin for water quality of water function areas in Lianyungang from 2010 to 2018, the single factor evaluation method is used to evaluate water function areas. It is simple in calculation and can quickly determine the water quality class by this method. However, the result is too heavy and extreme to evaluate the water pollution degree in the side of boundary conditions. The paper shows that FA-BP model is a multi-actor comprehensive evaluation model that can handle the boundary conditions very well. Compared with the traditional methods, FA-BP model also doesn't need to set weight values. It can effectively solve the problem of incompatibility of indicators and ambiguity of evaluation results.

1　Establishment of FA-BP model

1.1　Introduction

BP model is an intelligent algorithm that simulates information processing technology of the human nervous system. Consisting of an input layer, output layer and implied layer, it is a forward network based on error back propagation. So it has very strong non-linear mapping capability. Key performance is determined by topology, weights, and thresholds. The working principle can work out optimization problems by constantly updating weight values and thresholds with both forward propagation of signals and reverse propagation of errors to reduce error values of target. So, it is often applied to solve the water quality evaluation problem, because of the advantages of self-learning and self-adaptability, robustness, excellent nonlinear approximation ability and so on[21-22].

FA model is the latest algorithm in the field of intelligent optimization algorithm of imitation organism, which was proposed by Yang[23]. One firefly senses the intensity and flash frequency of other fireflies to determine the position and attraction of others to complete hunting or courtship behaviors. Experiments show that FA model is more effective and has a higher success rate in finding globally optimal solutions than other intelligence algorithms such as genetic algorithms[24]. Especially, it has great potential in dealing with NP issues[23]. The core parameters include the degree of attraction which determines the step size and brightness, which indicates the direction of individual movement. When these parameters are continuously updated, the firefly algorithm will be used to find the optimal solution in a certain field. The algorithm steps are as follows:

Step 1. Initialization of the total number (m), coefficient of light intensity absorption (γ), maximum absorptivity (β_0), step factor (α), maximum number of iterations (N), value of location of firefly ($x_i(t)$), fluorescein value ($l_i(t)$), and objective function ($\mathrm{f}(x_i(t))$).

Step 2. Finding all individuals with a greater fluorescein value than itself in its perceptual field based on the firefly algorithm. These individuals are then recorded as a neighborhood set. At time t, this set ($N_i(t)$) of the firefly i is expressed as

$$N_i(t)=\{j: \| x_i(t)-x_j(t) \| < r_d^i(t); l(t)<l_j(t)\} \quad (1)$$

$$r_{ij} = \| x_i(t)-x_j(t) \| = \sqrt{\sum_{d=1}^{D}(x_{i,d}-x_{j,d})^2} \quad (2)$$

where: r_{ij} is the Euclidean distance between firefly i and firefly j; D is the dimension of decision variables; and $r_d^i(t)$ is the decision radius of fireflies i at time t.

Step 3. Calculating relative brightness (I) and relative absorptivity (β) of each firefly one after another to determine the step value and moving direction.

$$I = I_0 \times e^{-\gamma r} \tag{3}$$

$$\beta(r) = \beta_0 e^{-\gamma r^2} \tag{4}$$

where: I_0 is maximum brightness; β_0 is the maximum absorptivity, i. e. , the absorptivity of firefly when $r=0$.

Step 4. Updating the location. Calculating brightness of firefly i and moving towards firefly j with the highest absorptivity value in the neighborhood.

$$x_i(k+1) = x_i(k) + \beta_0 e^{-\gamma r^2}(x_j(k) - x_i(k)) + \alpha(\text{rand}(0,1) - 0.5) \tag{5}$$

where: $x_i(k)$ is the position of x_i in the iteration of k times, and α usually takes 0 to 1.

Step 5. Finding the firefly with the highest absorptivity based on random walk

$$x_{\text{best}}(k) = x_{\text{best}}(k) + \alpha(\text{rand}(0,1) - 0.5) \tag{6}$$

Step 6. Updating the corresponding fluorescein value

$$l_i(t+1) = (1-\rho) l_i(t) + \gamma f(x_i(t)) \tag{7}$$

where: ρ is the renewal rate of fluorescein, and usually takes 0 to 1.

Step 7. Dynamically adjusting the decision radius (r_d^i) to update the firefly's decision field:

$$r_d^i(t+1) = \min\{r_s, \max\{0, r_d^i(t) + \varphi(n_i - |N_i(t)|)\}\} \tag{8}$$

where: r_s is individual perception radius; φ is the update rate of decision field; and n_i is the total number of individuals in the neighborhood field.

Step 8. Termination and output for optimal value.

1.2 Design of FA-BP model

Because of the limitation of searching the optimal solution with the gradient descent method, BP model is prone to "premature convergence" and unable to obtain the global optimal solution. FA model can be more effective and has a higher success rate in finding globally optimal solutions than other intelligence algorithms, e. g. genetic algorithm[25]. Every firefly contains all of the weight values and thresholds. FA model takes the objective function as the fitness function to search the global optimal solution accurately and efficiently. Then, the output solution including weight values and thresholds will be used as the initial value of BP model to go on to train surface water quality samples. Fig. 1 presents the flow chart.

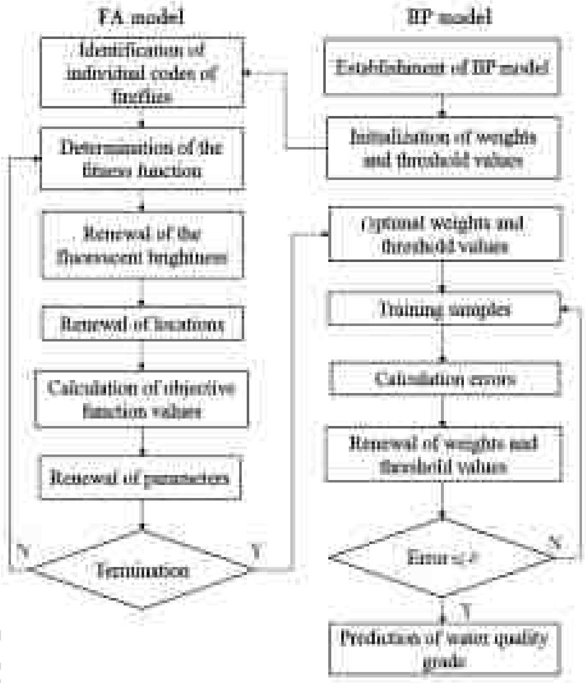

Fig. 1 Flow chart of FA-BP model

2 Data and evaluation methods

FA-BP model is applied to the evaluation of water quality of urban main rivers in Lianyungang, where the study selected five sections from Jiawei Bridge of Longwei River, Gongnong Bridge of Yudai River, Dapuhe Bridge of Dapu River, Ban Bridge of Paidan River, and Hehaitan Bridge of Dongyan River, respectively. There were 18 samples collected from above sections from 2016 to 2018. The evaluation benchmark is formulated in " Quality Standards for Surface Water Environment" , based on which the water quality is divided into five levels. It is necessary to attach great importance to water environment problems in Lianyungang City. There are many measures to improve the water environment, such as dredging works, cleaning, and treatment of aquatic plants, bank garbage and illegal construction along the rivers. Seven indicators are employed as evaluation factors, including dissolved oxygen (DO), ammonia (NH_3-N), permanganate index (COD_{Mn}), total phosphorus (TP), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and fluoride (F). Tab. 1 shows the measured data from 18 samples.

Tab. 1　Evaluation index values of water samples

Unit: mg/L

Sample number	DO	NH_3-N	COD_{Mn}	TP	F	BOD_5	COD
1	4.68	1.30	7.20	0.19	0.938	5.50	22
2	4.54	1.40	6.60	0.22	0.921	6.50	20
3	5.25	0.90	5.80	0.18	0.941	4.40	22
4	2.24	1.64	5.66	0.18	0.884	3.20	19
5	5.24	1.36	8.35	0.16	1.444	3.50	20
6	5.42	1.52	11.42	0.15	0.567	8.90	18
7	4.54	1.73	13.35	0.19	0.973	5.79	19
8	4.76	1.45	5.85	0.19	0.736	7.50	20
9	3.48	1.35	9.74	0.29	1.324	5.20	19
10	2.06	1.95	9.56	0.27	1.286	8.50	24
11	2.86	1.06	12.45	0.16	0.652	5.10	19
12	5.80	0.73	8.48	0.16	0.484	5.30	16
13	3.02	1.63	11.38	0.17	1.214	7.43	26
14	3.34	1.27	7.37	0.17	1.126	5.72	19
15	3.48	1.16	6.72	0.16	0.993	5.63	17
16	5.14	1.85	13.89	0.20	0.824	3.39	19
17	2.48	0.93	5.23	0.18	1.373	3.37	18
18	5.29	0.86	5.67	0.18	1.134	9.74	15

One of the water quality indexes represents one-dimension samples for BP model training. When multi-dimensional input is required in the water quality evaluation, the values of these indexes will be difficult for the evaluation because of different orders of magnitude. Thus, normalization is a good way to keep the order of magnitude of all indexes consistent. The paper takes a sigmoid function as a transfer function which maps negative infinity to positive infinity to [−1, 1]. The number of nodes in the input layer is set to 7. The hidden layer is 13. Output layer nodes are set to 5. The water quality evaluation class divides to I, II, III, IV, and V. The corresponding output results of training samples are [1, 0, 0, 0, 0], [0, 1, 0, 0, 0], [0, 0, 1, 0, 0], [0, 0, 0, 1, 0], and [0, 0, 0, 0, 1].

According to the water quality classification grade of "Quality Standards for Surface Water Environment", BP model takes the boundary value of each grade interval as an example. A total of 50 samples are randomly generated in each grade interval as training samples to evaluate 18 samples of major rivers in Lianyungang.

3　Result

3.1　Analysis of water quality evaluation

In order to verify the accuracy, 18 water samples were selected to evaluate using FA-BP model, Grey Incidence Analysis Algorithm (GIAA), and Fuzzy Comprehensive Evaluation Algorithm (FCEA)[26]. Fig. 2 shows the comparison results of three methods.

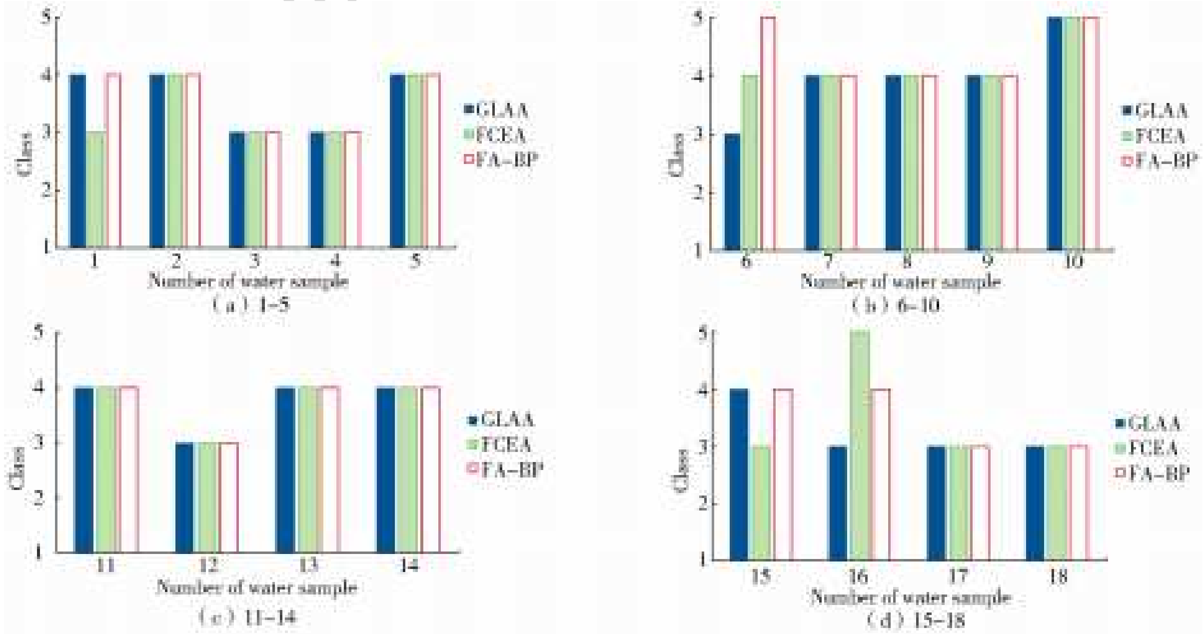

Fig. 2　Evaluation and comparison results of water samples

The evaluation results show that:(1) The water quality level of major rivers in Lianyungang City is mostly graded from class III to class IV. That means most rivers could pass the class III or class IV assessment standards of national or provincial, except several indexes exceed the standard exist including DO, NH_3-N, COD_{Mn}, BOD_5. (2) In 18 water samples, there are 14 water samples with the same evaluation results by three methods. FA-BP model has the same results as one of the other algorithms in 2 samples and diffident results with two algorithms in the rest. Detailed analyses are as follows.

(1) Evaluation results are class IV by both GIAA and FA-BP in 1, 15 samples. FCEA is class III. The reason is that the concentration of several indexes including DO, NH_3-N, COD_{Mn}, BOD_5, and COD have reached Class IV in 1, 15, but these values are closer to the upper limit of class III standard. The concentration of DO is 4.68 mg/L and COD_{Mn} is 7.2 mg/L. When many indicators are concentrated in any two water quality grade intervals, the results of evaluation could differ by GIAA. For example, a sample has 8 indicators, of which 4 indicators are class II and the others are class V. The results could be class II or class V by GIAA. The standard of water function area of Lianyungang demands to reach class III, but there are many rivers slightly polluted in Lianyungang. If FCEA is applied, the above rivers will pass standard of water function area. Therefore, the result will be not conducive to improvement and governance of water environment.

(2) There are three indexes of class V and three of class III in sample 6. Two water indexes of class V and four of class III in sample 16. It is unreasonable that the results of evaluation in 6 and 16 are class III by GIAA. Water sample that the number of class III indexes is roughly equal to the number of class V indexes. However, the impact of extreme over indexes of class V could be ignored by GLAA. In this situation, the evaluation result of FA-BP model is class V, which is more conducive to water quality improvement.

Water quality is often evaluated by FA-BP model, GIAA and FCEA. FCEA weakens the impact of the dividing line in different class of water quality, and the evaluation result is good. This method considers the influence of weights in the way of water quality, which is a comprehensive evaluation method. However, this method is difficult to determine the main pollutant indicators, especially heavy metals and toxic organic substances, which may be ignored. GIAA can effectively utilize all the monitoring indicators of water samples, and make the water quality weights allocation of each indicator participate in the final result. The evaluation result is more rigorous than FCEA. This method is applicable to the evaluation of water quality in the downstream development zones and irrigation areas. The evaluation process of FA-BP model is based on the random training samples generated from "surface water environmental quality standard", which is suitable for the water quality evaluation of water source areas and water function areas, and facilitates the implementation of the strictest water resource management.

Tab. 2 is water environment treatment measures from the 12th phase of the bulletin of water quality in Lianyungang city water function area in 2018. More funds will be allocated in water function area where water quality fails the assessment, so the utilization rate of water environment treatment funds will have been increased.

Tab. 2 Water environment treatment measures of different class in water function areas

Class	Treatment measures
I	Water quality is very safe. Focus on protection measures.
II	Water quality is very safe. Focus on protection measures.
III	Water quality is safe. Focus on protection measures and supervision. Prevention of external pollution.
IV	There are several indexes exceed the standard. If water quality passes the assessment of water function area, focus on protection measures and supervision. Prevention of external pollution. If water quality fails the assessment, it need to identify the type of pollution, take measures to control external pollution and carry out river dredging project.
V	There are some indexes exceed the standard. Special investigations on pollution sources are carried out. Comprehensive treatment of river pollution is carried out. The management needs to be strengthened.

3.2　Sensitivity analysis

FA-BP model is a multi-factor comprehensive evaluation. Evaluation results are affected by these indicators. To study on the impact the experiment chooses water samples of 1, 5, 6, 13 and 16 in Tab. 1. Selected indicators are divided into three groups. Frist group includes all indicators. Second group includes all indicators except for NH_3-N and COD_{Mn}, which are main pollutants of urban rivers in Lianyungang. Last groups includes all indicators except for F and COD, which do not exceed the standard. The results are showed in Tab. 3. When FA-BP model is used for water quality evaluation, the evaluation result will be affected by the main exceeding indexes. And the evaluation result is less affected by not exceeding indexes.

Tab. 3　Sensitivity analysis

Number	Group 1	Group 2	Group 3
1	IV	IV	IV
5	IV	III	IV
6	V	IV	V
13	IV	IV	IV
16	IV	III	IV

4　Conclusion

(1) FA-BP, GIAA, FCEA can all be applied in water evaluation in Lianyungang. The results show that the water quality of the rivers in Lianyungang City from 2016 to 2018 was generally rather well. The major indicators exceeding the standard includes NH_3-N and COD_{Mn}.

(2) FA-BP model can avoid setting weight values and reduce the interference of subjective factors. Compared with the other traditional methods, the problem of incompatibility of indicators and ambiguity of evaluation results, which are greatly affected by extreme indicators but hardly by normal indicators, can be effectively solved. It is more objective and reasonable for evaluation results by FA-BP model than the others.

(3) The analysis of time and space complexity needs further study of FA-BP model. Part of FA model sets a few parameters, but there is no standard for these parameters, and the research of the sensitivity analysis of these parameters is very necessary for further work.

References:

[1] MIU W L, HUANG J S, DING J G, et al. Pollution Status and remediation technologies of malodorous black water body in China[J]. Journal of Changjiang Academy of Sciences, 2017, 34(11): 153-158. (in Chinese) DOI: 10.11988/ckyyb.20170730.

[2] XIE D P, LI K M, JIANG D, et al. Study on effect of polluted sediments bioremediation on water body remediation of polluted urban rivers[J]. Journal of Environmental Engineering, 2009, 3(8): 1447-1453. (in Chinese) DOI: 10.3960/j.issn.1673-9108.2009.03.112.

[3] YU G W, LEI H Y, LIU K S, et al. In situ sediment remediation technology for control of black and odorous water in Tidal River[J]. China Water Supply & Wastewater, 2007(9): 5-9, 14. (in Chinese) DOI: 10.3321/j.issn:1000-4602.2007.09.002.

[4] CHENG M Q, MENG Q F. Study on comprehensive treatment methods for black and stink water body of Tiansha River in Guangdong[J]. Yangtze River, 2017, 48(S2): 32-35. (in Chinese) DOI: 10.16232/j.cnki.1001-4179.2017.S2.009.

[5] FU J B. Causes of black odor in village-level rivers in Shanghai suburbs and countermeasures for water environment treatment[J]. China Rural Water and Hydropower, 2011(12): 31-32, 35. (in Chinese) DOI: 10.3969/j.issn.1007-2284.2011.12.007.

[6] YANG Z, NIU G M. Analysis on coordinated governance of water pollution in Beijing-Tianjin-Hebei region from basin perspective[J]. Yangtze River, 2019, 50(9): 6-12. (in Chinese) DOI: 10.16232/j.cnki.1001-4179.2019.09.002.

[7] MENG W. Construction of technology system for watershed water pollution treatment and management-exploration and practice of the major water program in Liaohe River basin[J]. China Engineering Science, 2013, 15(3): 4-10. (in Chinese) DOI: 10.3969/j.issn.1009-1742.2013.03.003.

[8] LI J Y, PENG Y H, LIU Z Y, et al. Analysis of evaluation of surface water irrigation water quality in Heilongjiang Province[J]. Journal of Irrigation and Drainage, 2019, 38(12): 115-120. (in Chinese) DOI: 10.13522/j.cnki.ggps.2019126.

[9] JIANG B, SUN M, JI Y K, et al. Fuzzy comprehensive evaluation of surface water quality based on entropy method[J]. Journal of Irrigation and Drainage, 2018, 37(S1): 47-50. (in Chinese) DOI: 10.13522/j.cnki.ggps.

2016.0274.

[10] SHAO J, WANG Z X, et, al. Study and assessment on surface water resources in Ecuador[J]. Yangtze River, 2017, 48(22): 73-77. (in Chinese) DOI: 10.16232/j.cnki.1001-4179.2017.22.016.

[11] PAN L, HUANG X R, WEI X Y, et, al. A comparative analysis of three common water quality evaluation methods[J]. China Rural Water and Hydropower, 2019(6): 51-55. (in Chinese) DOI: 10.3969/j.issn.1007-2284.2019.06.010.

[12] DAI J F, ZHANG X H, WANG D Q, et, al. An assessment of river water quality in the Beibu gulf economic zone[J]. China Rural Water and Hydropower, 2012(1): 21-24. (in Chinese) DOI: 10.3969/j.issn.1007-2284.2012.01.005.

[13] ZHANG X J, XU Z M, SONG X Y, et, al. Application and study of several water quality evaluation method in rivers flowing into Qinghai Lake[J]. Environmental Engineering, 2013, 31(1): 117-121. (in Chinese) DOI: 10.3960/j.issn.1673-9108.2013.01.031.

[14] SUN J, HAN P L, WANG C, et, al. Study on the comprehensive evaluation of water quality status of the middle route main channel of the South-to-North Water Diversion Project[J]. South-to-North Water Science & Technology, 2019, 17(6): 102-112. (in Chinese) DOI: 10.13476/j.cnki.nsbdqk.2019.0141.

[15] XU D M, SHAO L, XU M C, et al. Application of variable fuzzy assessment model based on game theory in water quality evaluation[J]. Water Saving Irrigation, 2019(10): 60-63. (in Chinese) DOI: 10.3969/j.issn.1007-4929.2019.10.013.

[16] LI H H, XING J, LI X Z, et, al. Water quality evaluation model based on BP neural network for Xiaolangdi Jiyuan section of Yellow River[J]. Water Saving Irrigation, 2014(6): 57-59. (in Chinese) DOI: 10.3969/j.issn.1007-4929.2014.06.017.

[17] XIANG S L, WU C B, YAN G Q. Research on groundwater quality evaluation and forecasting system based on GIS[J]. Hydrogeological Engineering Geology, 2007(1): 123-125. (in Chinese) DOI: 10.3969/j.issn.1000-3665.2007.01.028.

[18] WANG Y M, SUN X L, CAO S L, et, al. Study on flood inverse-routing in river channel based on BP neural network[J]. Hydropower Energy Science, 2016, 34(3): 49-51, 54. (in Chinese) DOI: 10.7960/j.issn.1000-7709.2016.03.019.

[19] DU S S, WANG H Q, LIU Z Y, et, al. Improved model of groundwater quality evaluation based on artificial neural network[J]. Journal of Beijing Normal University (Natural Science), 2014, 50(4): 424-428. (in Chinese) DOI: 10.4160/j.issn.0476-0301.2014.04.092.

[20] FENG D Q, GUO Y. Application of improved BP neural networks based on Genetic Algorithm s to groundwater quality evaluation[J]. Journal of Zhengzhou University (Engineering), 2009, 30(3): 126-129. (in Chinese) DOI: 10.3969/j.issn.1671-6833.2009.03.032.

[21] CHEN M. Principles and examples of neural network in MATLAB[M]. Beijing: Tsinghua University Press, 2013. (in Chinese)

[22] LIU D, LI S, FU Q, et al. Comprehensive evaluation method of groundwater quality based on BP network optimized by Krill Herd Algorithm[J]. Journal of Agricultural Machinery, 2018, 49(9): 275-284. (in Chinese) DOI: 10.6041/j.issn.1000-1298.2018.09.032.

[23] YANG X S. Firefly algorithm, stochastic test functions and design optimization[J]. International Journal of Bio-Inspired Computation, 2010, 2(2): 78-84. DOI: 10.1504/IJBIC.2010.032124.

[24] GONG Y C, ZHANG Y X, DING F, et, al. Projection pursuit model for assessment of groundwater quality based on firefly algorithm[J]. Journal of China University of Mining and Technology, 2015, 44(3): 566-572. (in Chinese) DOI: 10.13247/j.cnki.jcumt.000352.

[25] GONG Y C, ZHANG Y X, DING F, et, al. Grey relation-projection pursuit model for assessment of groundwater quality based on Firefly Algorithm[J]. Journal of Basic Science and Engineering, 2015, 23(3): 512-521. (in Chinese) DOI: 10.16058/j.issn.1005-0930.2015.03.010.

[26] AN L S. Comprehensive study on surface water quality assessment methods and water quality prediction models[D]. Qingdao: Qingdao University, 2009. (in Chinese)