



PSR-BP Neural Network-Based Health Assessment of the Huangshui Plateau Urban Wetlands in China

Lingling Tong^{1,2}, Xufeng Mao^{1,2,3*}, Xiuhua Song⁴, Xiaoyan Wei^{5*}, Wenjia Tang³, Yanfang Deng⁶, Hongyan Yu⁶, Zhuo Deng⁷, Feng Xiao⁸, Huakun Zhou⁹ and Xinan Yin¹⁰

¹ Key Laboratory of Tibetan Plateau Land Surface Processes and Ecological Conservation, Ministry of Education, Qinghai Normal University, Xining, China, ² Qinghai Province Key Laboratory of Physical Geography and Environmental Process, College of Geographical Science, Qinghai Normal University, Xining, China, ³ State Key Laboratory for Environmental Protection Monitoring and Assessment of the Qinghai-Xizang Plateau, Xining, China, ⁴ School of Economic and Management, Qinghai Normal University, Xining, China, ⁵ Management and Service Center for Huangshui National Wetland Park, Xining, China, ⁶ Management and Service Center of Qilian Mountain National Park, Xining, China, ⁷ School of Landscape Architecture, Beijing Forestry University, Beijing, China, ⁸ Forest and Grass Bureau of Qinghai Province, Xining, China, ⁹ Key Laboratory of Cold Regions Restoration Ecology, Xining, China, ¹⁰ School of Environmental Science, Beijing Normal University, Beijing, China

OPEN ACCESS

Edited by:

Haitao Wu,

Northeast Institute of Geography and Agroecology (CAS), China

Reviewed by:

Junhong Bai,

Beijing Normal University, China

Arnaldo Marin,

University of Murcia, Spain

*Correspondence:

Xufeng Mao

maoxufeng@yeah.net

Xiaoyan Wei

weixiaoyan4477@163.com

Specialty section:

This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: 31 January 2022

Accepted: 20 May 2022

Published: 09 June 2022

Citation:

Tong L, Mao X, Song X, Wei X, Tang W, Deng Y, Yu H, Deng Z, Xiao F, Zhou H and Yin X (2022) PSR-BP Neural Network-Based Health Assessment of the Huangshui Plateau Urban Wetlands in China. *Front. Ecol. Evol.* 10:866597. doi: 10.3389/fevo.2022.866597

Wetland health assessment provides important basis for wetland restoration and management. However, it is quite tricky to select proper indicators from multiple assessment indicators that can truly reflect the health state of urban wetlands. In an attempt to address these problems, a pressure-state-response (PSR) and back propagation artificial neural network (BP) conjoined model was established for health assessment of several plateau urban wetlands in Xining City, China. The model was driven and verified through field monitoring and social questionnaire data for 4 consecutive years from 2016 to 2019. Results indicate that: (1) Eight health evaluation indexes, including population density, eutrophication level, increasing humidity, carbon dioxide absorption, air purifying, recreation, wetland management level and investment in ecological construction and protection were selected from 45 input indexes. (2) The health index of Huangshui National Wetland Park has been increasing year by year, with an average of comprehensive health score of 0.746, 0.790, 0.884, and 0.877, respectively. The indicators that contributed the most to the restoration effect were leisure and entertainment service value (2016), carbon dioxide absorption service value (2017), eutrophication (2018), and wetland management level (2019), respectively. (3) Compared with the single PSR method, the advantages of this method include; There are fewer evaluation indicators, more accurate results (excluding the interference of some highly variable indicators) and more sensitive to environmental changes. The current study proposed a novel method that may provide additional accurate and refined indicators for urban wetland health assessment.

Keywords: BP neural network, plateau urban wetland, health evaluation, evaluation index, pressure-state-response (PSR) model

INTRODUCTION

Urban wetlands refer to wetlands distributed in cities and towns (Sun et al., 2004; Robert et al., 2021). As an important part of the urban ecological environment, urban wetlands are public open space dominated by natural landscapes (Bolund and Hunhammar, 1999; Wang et al., 2006). They present many advantages, such as controlling flood and waterlogging, providing leisure and entertainment environments, and fulfilling scientific research and education purposes with their ecosystem-managing and cultural services also playing relatively important roles (Boyer and Polasky, 2004; Ho and Richardson, 2013; McInnes, 2014; Wahlroos et al., 2015; Jonathan et al., 2019; Stefanak, 2019; Wei et al., 2020; Liu et al., 2021; Li et al., 2022). Rapid urbanization has made urban wetlands one of the fastest shrinking ecosystems (Holland et al., 1995; Cui et al., 2004; Lee et al., 2006; Asomani-Boateng, 2019; Jing et al., 2020; Wang, 2020).

People are gradually realizing the importance of wetlands in urban ecological security and ecosystem services. Different scales and types of wetland ecological restoration have been carried out (Asomani-Boateng, 2019), such as the ecological restoration of Xixi National Wetland Park (Liu and Lu, 2021) and the functional restoration of the Yellow River wetland ecosystem (Xia et al., 2006) in China. Traditional wetland health assessment methods mainly include grey clustering analysis (Zhou and Xu, 2006; Zhang et al., 2013; Zou et al., 2013; Jiao et al., 2016; Wang et al., 2018; Asare et al., 2021), comprehensive index analysis and fuzzy comprehensive evaluation analysis (Zhang et al., 2010; Zhang and Yang, 2012; Wu et al., 2015; Sutton-Grier and Sandifer, 2019; Fang et al., 2021). Due to the existence of certain supervision in the weight and weight functions of each evaluation indicator, whether such health evaluation results truly reflect the health situation needs to be further explored.

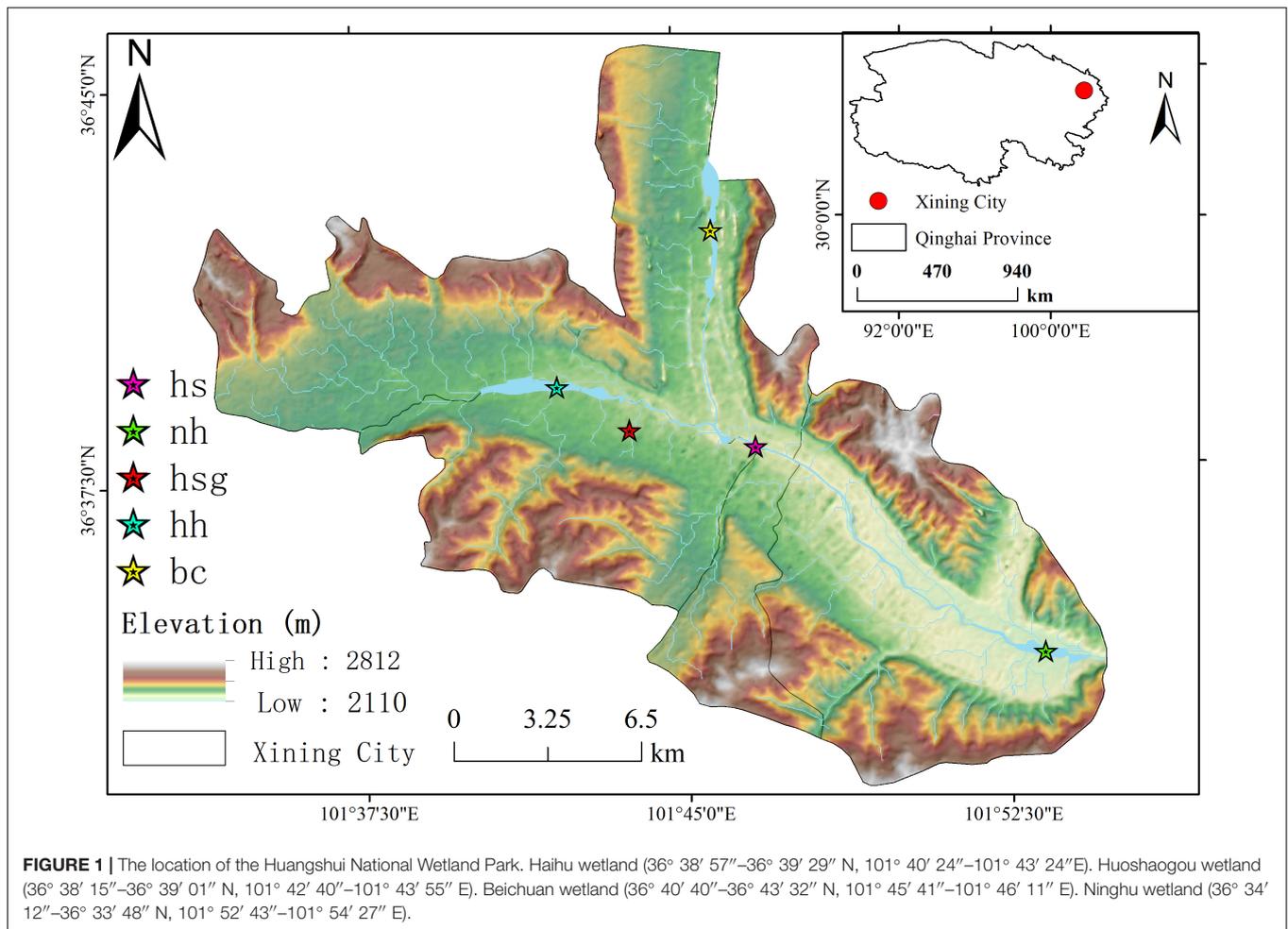
Huangshui National Wetland Park, located in a plateau city in China, consists of rivers and artificial wetlands. Since a pilot scheme was launched in 2013, a series of restoration projects have been carried out. The transformation of sponge city, that is, the combination of wetland natural ecology and green technology to form a rainwater and flood control and utilization system (Hu et al., 2017; Ahn and Schmidt, 2019), has improved the hydrological cycle and water ecosystem, and the CHI (comprehensive health index) has increased from 0.568 in 2018 to 0.620 in 2019. Bird habitat islands and wetland plant plantings have put in place to create habitats for wild birds. The species of wild birds has increased from 89 in 2017 to 116 in 2019 (an increase of 27 species) at a rate of 30.33% (Mao et al., 2019); Biological monitoring technology, isotope analysis technology, and ecological network analysis technology have been adopted to create large enclosure systems for continuous monitoring, and build a quantitative lake ecological network model. Treatment of algal blooms facilitates the improvement of water quality, and the total phosphorus in water quality has improved from class V to class II and III during the treatment period (Mao and Wei, 2015; Mao et al., 2019; Wu et al., 2021). However, because restoration projects are often

carried out with a specific goal, the final restoration effect exhibit significant differences. These differences include (1) time difference: while the initial effect of the restoration project was good, the effect diminished due to a lack of maintenance and investment in the later stage; (2) spatial difference: the effect of the restoration area was superior, but with unacceptable effect of the unrestored area; (3) differences in response indicators: for example, while dredging may bring about an improvement in water quality, it may also have a negative impact on benthic organisms. Thus, eventually, the health evaluation results document significant differences and variations, and it is difficult to find indicators that truly represent the health of wetland ecosystems (Mao et al., 2019).

The BP neural network is a non-linear dynamic system built on artificial intelligence (Rheinhardt et al., 1997; Cao et al., 2006; Bian et al., 2014; Wu and Feng, 2018; Wei et al., 2021). Due to the characteristics of self-learning and self-adaptation, the weights and thresholds of the network are transformed according to the existing information in the data to reduce artificial factors and better fit the relationship between evaluation indicators and wetland health (Kuo et al., 2007; Hanbay et al., 2008; Ferreira et al., 2011; Han et al., 2021). On one hand, if pressure-state-response (PSR) with BP artificial neural networks are combined, the pressure, state, and response indicators are to the greatest extent incorporated into the health evaluation indicators; on the other hand, the self-learning and adaptive ability of the BP artificial neural network are utilized. This indicates the advantage of a stronger and better fitting ability of the relationship between evaluation indicators and wetland health. This strategy may be part of the measures to screen for indicators that truly reflect the health of urban wetland ecosystems. Taking Xining Huangshui Wetlands as the research areas, supported by field plant quadrats, environmental monitoring data, and social survey data from 2016 to 2019, this study used the Analytic Hierarchy Process (AHP) method to provide comprehensive index weight, and construct a comprehensive health evaluation model suitable for plateau city wetlands based on the PSR-BP neural network model. This is aimed at finding the evaluation factors suitable for plateau city wetland health, evaluate the health status of wetland restoration, find the synergy and trade-off relationship between wetland ecosystem evaluation factors, score the key influencing factors of national wetland health in plateau cities, and provide key methods and theoretical support for wetland improvement and protection projects in plateau cities.

STUDY AREA

The study area is located in the urban area of Xining City, Qinghai Province (Figure 1). It is located in the eastern part of Qinghai Province and the middle of Hehuang Valley, with an average altitude of around 2,261 m. The terrain is high in the northwest and low in the southeast, belonging to the plateau cold temperate semi-arid climate zone, with low air pressure, long sunshine, and large temperature difference between day and night. The annual average temperature is 5.0°C, and the average precipitation is



506.4 mm. The annual sunshine time is 2,390.1 h, and the annual average wind speed is 2.0 m/s.

The Huangshui National Wetland Park is located in an urban area. The surrounding residential areas, commercial areas, and roads are dense, with several sources of pollution and poor water quality. Among them, the Haihu wetland and Huoshaogou were transformed into sponge cities in 2016. With purification capacity of the wetland ecological treatment system and the restoration capacity of the water ecosystem, the functioning of the bird habitat strengthened, and the functions of science popularization, publicity and education, leisure and entertainment further improved, wetland ecosystem services have gradually stabilized. Beichuan wetland has a large water area. Ninghu wetland is an artificial wetland. In 2017, wetland vegetation ecological restoration and bird habitat restoration were undertaken for the two wetlands simultaneously, so that the water quality was purified and the biodiversity was improved. However, in this process of sponge city reconstruction, wetland vegetation restoration and bird habitat restoration, along with other ecological restoration projects such as water quality restoration, there are temporal and spatial differences in the effect of ecological restoration. Further impacts of the performance of different indicators may also be good or bad, making it

difficult to carry out a scientific evaluation of the effect of wetland restoration.

MATERIALS AND METHODS

The Pressure-State-Response-Back Propagation Neural Network Assessment Model

Pressure-state-response-BP neural network evaluation model is a model established by the combination of PSR model (Zhang et al., 2010) and BP neural network assessment model (Han et al., 2021). According to the PSR model, we selected the pressure-state-response index, a total of 45 wetland evaluation indexes, and gave the index weight according to the AHP method and Delphi method, and established the general PSR wetland health evaluation model to evaluate the wetland health status. 45 indexes selected based on PSR model were used as the input layer of BP neural network model to output the weight of 45 indexes. Finally, 8 wetland evaluation indexes with large weight were selected to establish PSR-BP neural network wetland health evaluation model.

Methods

Normalization Treatment on Pressure-State-Response Indicators

We used the 2016–2019 field monitoring, experimental, and social survey data, as well as Qinghai Provincial Statistical Yearbook data as the basis, and converted them into the pressure, state, and response indicators (**Supplementary Table 1**). According to the above pressure state response index and index scoring standard, data were standardized in combination with the formula (1), so that the value was between 0 and 1.

$$x'_i = \frac{X_i}{\sum_{i=1}^m X_i} \quad (1)$$

Where m is the number of samples.

Analytic Hierarchy Process and Delphi Method

Specific evaluation methods: Based on the combination of AHP and Delphi, the judgment matrix of the relative importance of the criteria layer indicators was constructed (**Table 1**). After the consistency test formula passed ($CR = 0.03319 < 0.1$), the weight of the three-criteria-layer indicators of pressure index, state index, and response index was calculated as 0.258, 0.637, and 0.105, respectively.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

Back Propagation Neural Network Methodology

The Huangshui wetland health assessment network model was formed by the Levenberg Marquardt algorithm. The network used the mean square error algorithm to compute the error, and the maximum allowable number of iterations was 1,000. (1) Input layer: the health evaluation indicators of the Huangshui National Wetland Park served as the input layer of the model, and there were 45 input nodes. (2) Output layer: the comprehensive health evaluation index of the Huangshui National Wetland Park was invoked as the output layer of the model, and there was one output node. (3) Hidden layer: as the calculation method of the node number of this layer has not yet displayed a definite regularity, the empirical formula was used. (4) In the formula, the number of hidden layer nodes is n ; the number of input layer nodes is m ; the number of output layer nodes a ; l is a random integer from 1 to 10. The calculated number of hidden layer nodes varied from 7 to 16. When the mean square error (MSE) reached the minimum, the corresponding optimal number of nodes was $n = \sqrt{m + a} + l$ (Mo et al., 2009). (2) The average value and standard deviation of the eight selected evaluation indexes are presented in the **Supplementary Material**.

Comprehensive Health Index

Combined with the results of wetland monitoring data from 2016 to 2019, the scoring criteria for the restoration effect of each evaluation index of wetland were probed, and Comprehensive

Health Index (CHI) was used for wetland health evaluation. After the BP neural network model determined the index weight of the sub criterion layer, the expert scoring method was used to identify the pressure, state and response index weight of the criterion layer, and complete the weighting of all standardized index values. The CHI of each wetland park was obtained according to the calculation formula (4)

$$CHI = \sum_{i=1}^m W_i \cdot X_i \quad (4)$$

Where W_i is the comprehensive weight of each indicator, and X_i is the health index.

A three-layer BP neural network model was established based on the Neural Net Fitting toolbox in MATLAB, and a PSR-BP neural network-based wetland health assessment model was constructed (**Figure 2**).

Trade-Off Analysis and Driving Factors Analysis

The trade-off analysis of urban health assessment indicators mainly adopted the Pearson correlations correlation analysis method. This analysis is primarily used to assess the correlation degree between multiple index factors. SPSS27 was used to analyze the correlation of the weight of Huangshui humidity health assessment index of 45 plateau cities extracted from the BP neural network model.

Data Sources

The monitoring data were collected from March to October every year from 2016 to 2019, and the wetland restoration area was monitored and sampled for details (**Supplementary Table 1**). Remote sensing data were obtained from the Geospatial Data Cloud website. After interpretation of remote sensing images in 2021, the land-use map was obtained. It was split into cultivated land, forest land, grassland, wetland, residential land, unused land and other types of land, and a general map of the study area was drawn (**Figure 1**). Bird data were obtained from the Huangshui National Wetland Park Management Office and their the Shannon-Wiener index and the evenness were calculated (Jiang, 2001). Wetland Park Management Office. Based on PSR wetland health evaluation system, 45 evaluation indexes were passed through MATLAB software when the error value is 2.635×10^{-11} , extracted the weight and threshold vector of the index. After Origin21, the average weight of 45 indicators is presented in the order from large to small, and the weights of pressure, state and response indicators were presented in a comparative bar graph; Based on PSR-BP neural network model, the comprehensive health score of Huangshui wetland were presented by superimposing columnar statistical chart with Origin21 software, and the scores of five wetlands were presented by broken line chart. The evaluation results of PSR model and PSR-BP model were presented by the standard variation curve function of Origin21 software.

TABLE 1 | Relative importance judgment matrix and ranking.

	Pressure index	Status index	Response index	Wi
Pressure index	1.00	0.33	3.00	0.258
Status index	3.00	1.00	5.00	0.637
Response index	0.33	0.20	1.00	0.105

$CR = 0.03319 < 0.1$.

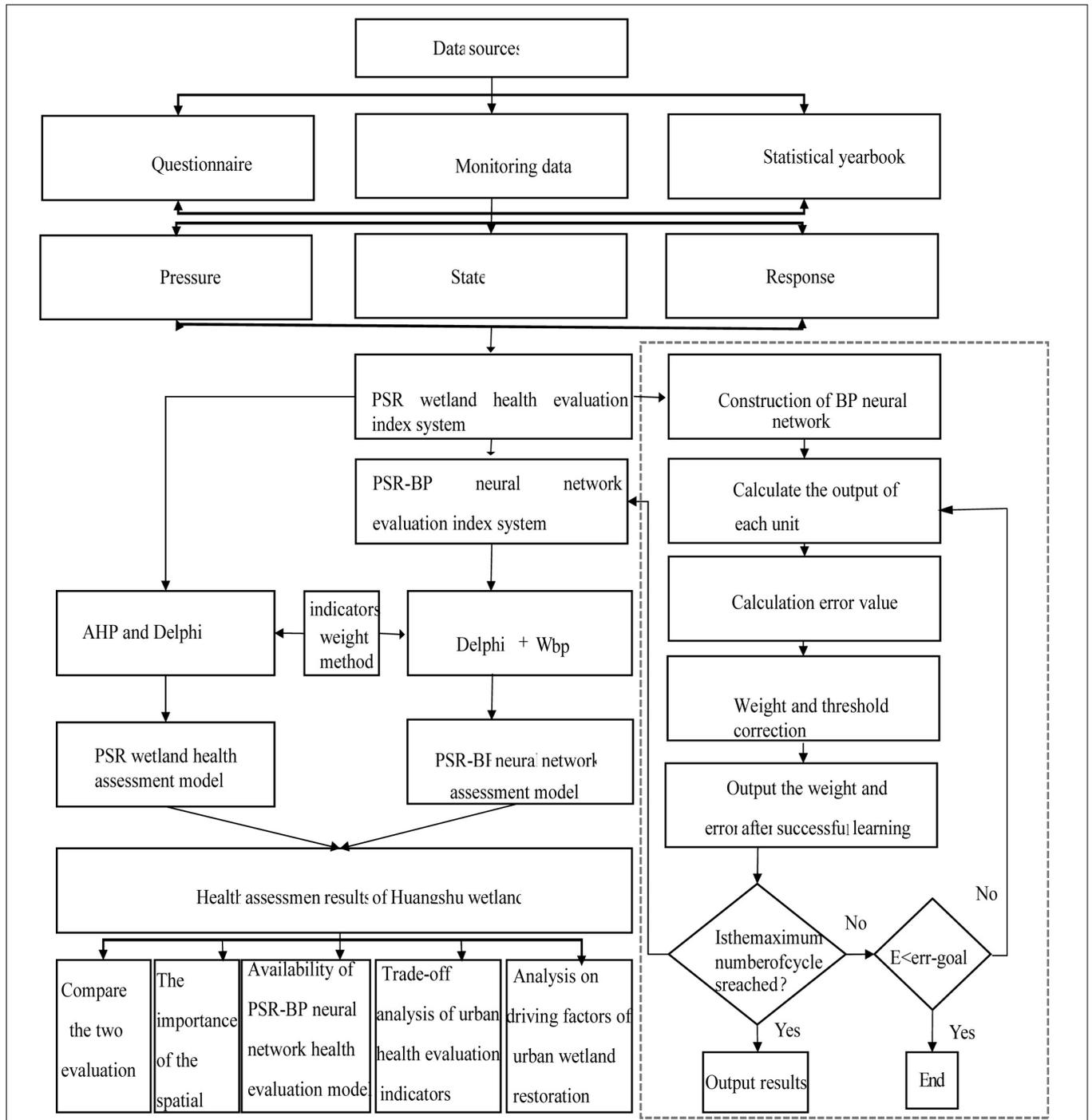


FIGURE 2 | PSR-BP neural-network-based wetland health assessment model.

RESULTS

Screening of Health Evaluation Indicators Based on the Back Propagation Neural Network Model

Based on the trained PSR-BP neural network model, the weight and threshold vector when the error value is 2.635×10^{-11} was extracted using MATLAB, and the weight mean values were presented in descending order using Origin21 (Figure 3). We observed that among the 45 Huangshui national wetland health evaluation indicators, the average weight of 21 indicators was positive, indicating that there were 21 evaluation indicators suitable for evaluating the health status of plateau urban wetlands. According to the average weight of the Huangshui national wetland health evaluation indicators from 2016 to 2019, the top eight indicators were identified as increasing humidity > wetland management level > eutrophication > absorption of carbon dioxide > leisure and entertainment > population density > investment in ecological construction and protection > air purification. (1) Pressure indicators: compared with natural pressure, anthropogenic pressure (population density, $W = 0.083$) had a more marked effect on the plateau wetland ecosystem. (2) Wetland state indicators: increasing humidity services ($W = 0.110$) played a positive role in promoting the healthy and sustainable development of the plateau urban wetland ecosystem, and this indicator acts jointly with carbon dioxide absorption ($W = 0.093$), purifying the air ($W = 0.065$), regulating services and entertainment ($W = 0.088$) to promote the healthy development of wetlands for cities with arid climates on the plateau. The improvement of water eutrophication ($W = 0.093$) greatly affected the evaluation index of the wetland. (3) Response indicators: obviously, the management level of wetlands (average weight = 0.107), ecological construction and protection investment ($W = 0.071$), and other response indicators are positively correlated with the health of wetland ecosystems. Therefore, to improve the management level of wetland factors, it is necessary to increase investment in wetland ecological construction and protection to improve the wetland ecosystem, and to promote sustainable development.

Health Evaluation Results Using the Pressure-State-Response-Back Propagation Neural Network Method

From the health evaluation results using the PSR-BP artificial neural network, it can be seen that (1) the health index of the Huangshui National Wetland Park has been increasing year by year, and the comprehensive scores were 0.746 (2016), 0.790 (2017), 0.884 (2018), and 0.877 (2019); (2) the spatial variation of PSR-BP neural network health comprehensive score was Beichuan Wetland > Haihu Wetland > Huoshaogou > Huangshui River > Ninghu Wetland (Figure 4); (3) among the three PSR types of indicators, the state indicators had the best recovery, while the comprehensive score of the response indicators

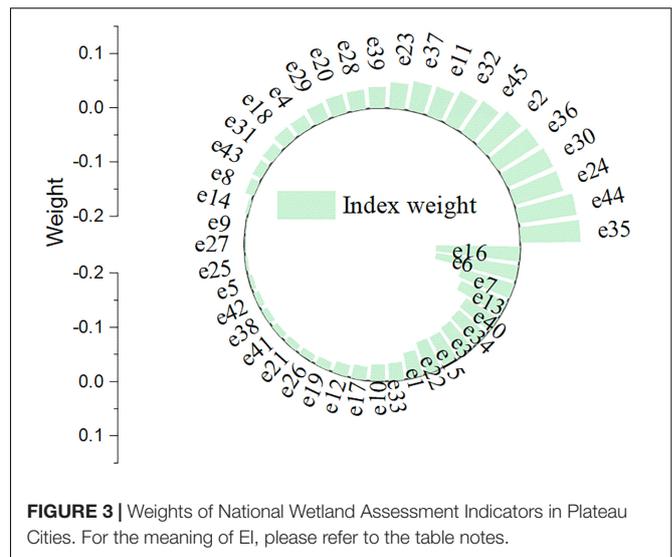


FIGURE 3 | Weights of National Wetland Assessment Indicators in Plateau Cities. For the meaning of EI, please refer to the table notes.

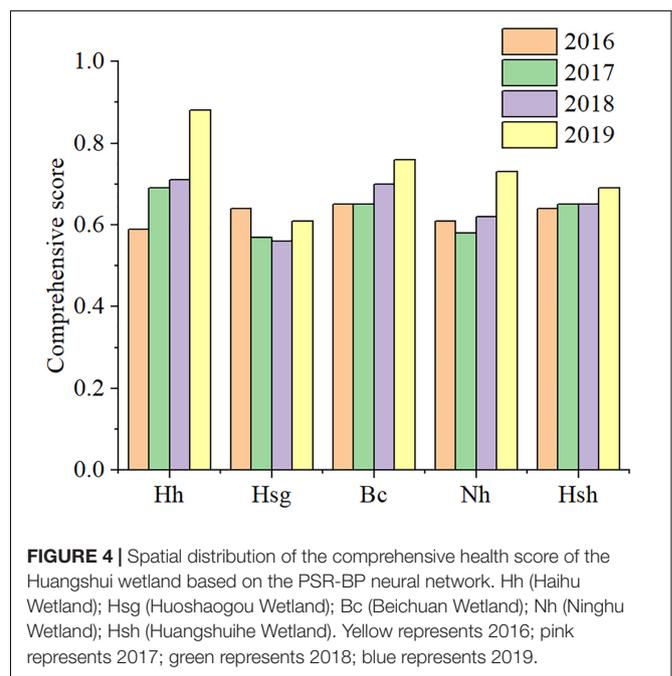
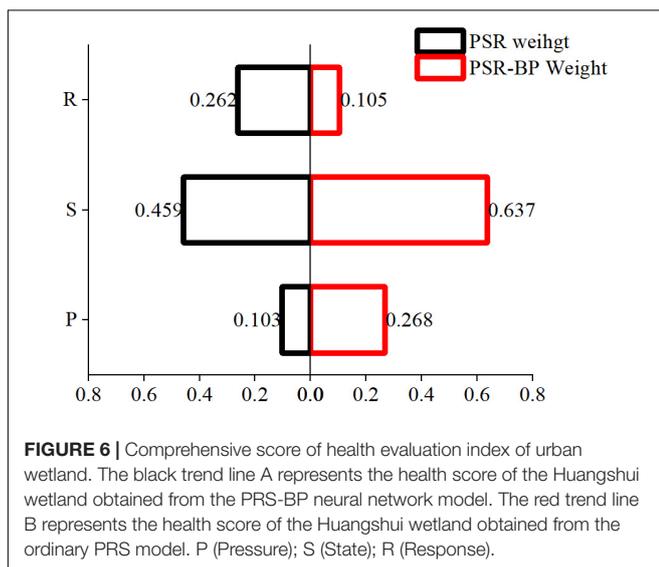
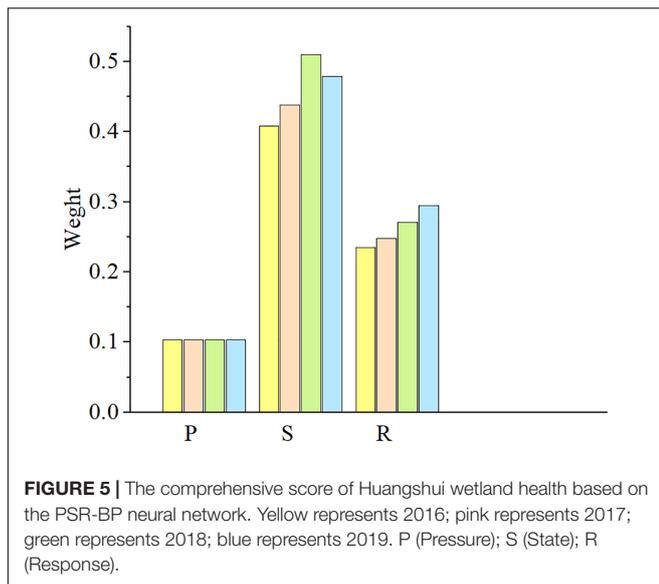


FIGURE 4 | Spatial distribution of the comprehensive health score of the Huangshui wetland based on the PSR-BP neural network. Hh (Haihu Wetland); Hsg (Huoshaogou Wetland); Bc (Beichuan Wetland); Nh (Ninghu Wetland); Hsh (Huangshuihe Wetland). Yellow represents 2016; pink represents 2017; green represents 2018; blue represents 2019.

increased year by year, showing a gradually increasing impact on the restoration of the Huangshui (Figure 5); (4) The top indicators with a major contribution to the restoration were leisure and entertainment service value (2016), carbon dioxide absorption service (2017), eutrophication (2018), and wetland management level (2019).

Comparison Between Pressure-State-Response Based and Pressure-State-Response-Back Propagation-Based Evaluation Results

Compared with the general PSR evaluation results, the PSR-BP neural network evaluation results were found to be



parallel. For comparing the scores of the three comprehensive indicators (Figure 6), based on the results of the general PSR health evaluation, the weight of the stress, state, and response indicators was 0.258, 0.637, and 0.105, respectively. The status indicators were the most important ones for the health restoration of the Huangshui wetlands (Figure 6). The comparison of comprehensive health scores was consistent with the evaluation outcome of the previous result documenting an increase year by year (Figure 7). For the comparison of restoration contribution indicators, in the general PSR evaluation results, the indicators that contributed the most to the restoration were leisure and entertainment service value (2016), cumulative soil erosion area, land-use intensity (2017), eutrophication (2018), and plant height (2019). In 2016 and 2018, the indicators with the largest contribution to the annual recovery were consistent.

DISCUSSION

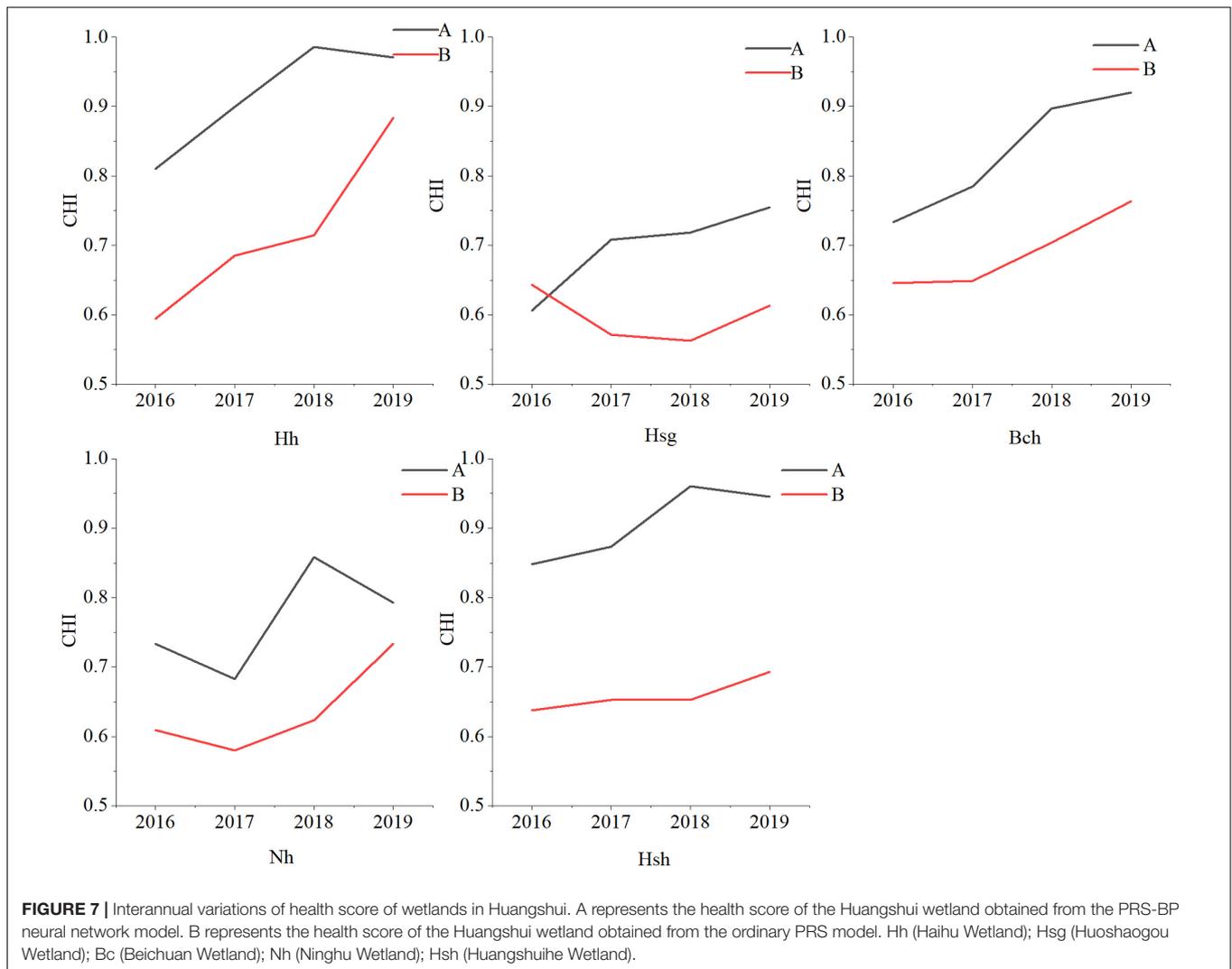
Advantages of Pressure-State-Response-Back Propagation Neural Network in Wetland Evaluation

The advantages of this research method lie in (1) giving the index weight: the PSR-BP neural network wetland health evaluation model adopted the combination of AHP method and BP artificial neural network to give the index weight. Compared with the single PSR model, the index weight reduced subjectivity and was more objective and accurate. (2) screening of indicators: This model was fitted with the indicator data for four consecutive years, so that the selected evaluation indicators were more in line with the recovery characteristics of the study area. (Figures 8, 9) show that the trend of A curve is more in line with the wetland health status, and the evaluation indicators are more targeted and representative; The representative indicators suitable for evaluating the health of plateau urban wetland ecosystem were found: population density, eutrophication level, increasing humidity, carbon dioxide absorption, air purifying, recreation, wetland management level and investment in ecological construction and protection.

New Insights Into the Wetland Management Based on Spatial Distribution of Pressure-State-Response-Back Propagation Neural-Network-Based CHI and Trade-Off Between Indicators

The ecological environment of the wetlands in Huangshui National Wetland Park is divers, and the objectives and effects of restoration projects are different. The bird habitats and the four wetlands vegetation were restored, and the number and diversity of wild birds in the wetland were significantly improved. Among them (Figure 10), Beichuan, with the largest water area, had the highest Shannon-Wiener index ($H = 2.91$). Through the construction of constructed wetland, vegetation ecological restoration combined different vegetation reasonably (merged plants, floating plants, and floating left plants). The average richness and coverage of wetland plants increased dramatically. The average coverage of the four wetlands was up to 81% (Mao et al., 2018), and the vegetation biomass of Ninghu wetland increased significantly; The restoration projects from 2016 to 2017 mainly focused on the water purification project of Haihu wetland, and carried out external pollution control, constructed wetland construction and wetland desilting. The total phosphorus pollution of water quality was decreased, the phenomenon of eutrophication was considerably improved (Figure 8), and the improvement rate of wetland score was arrived at 22.10% (Figure 4).

Analyze the spatial differences of PSR-BP neural network based on artificial neural network, and draw new the implications for more accurate management, and conservation of alpine urban wetlands:



- (1). There are significant differences in the spatial distribution of wetlands. The selection of evaluation indicators should consider the characteristics of wetland ecological environment, regional development status, risks and pressures faced, so as to improve the accuracy of the health evaluation results.
- (2). The bird habitat restoration project is appropriate for wetlands with large water area and sufficient living space to ensure the safe distance of birds. At the same time, in order to prevent habitat destruction, it is necessary to reduce the Land use intensity ($P < 0.01$) and limit the water consumption for irrigated agriculture ($P < 0.05$, **Figure 11**) in the wetland, so as to improve the survival rate of birds.
- (3). While considering the specific water pollution indicators, the water purification measures should strengthen the external pollution control (domestic sewage, urban road surface rainwater and industrial sewage) to control the source and intercept the sewage, so as to ensure the improvement and play of the ecological purification function of the wetland.
- (4). Considering the characteristics of wetland environmental pollution, the vegetation reorganization of constructed wetland fully combines the purification function of wetland on the botanical characteristics of plants. Targeted plant reorganization can purify the main pollutants, improve the green space coverage and improve the carbon dioxide fixation of wetland ($r = 0.746$, $P < 0.01$).

Uncertainty or Deficiency of the Model

Effective evaluation results require accurate analysis and evaluation of the sources uncertainty (Hines et al., 2018). Here we calculated the average values of three secondary level indicators (Pressure, State, and Response) and their standard deviation (\pm SD) to evaluate the potential uncertainty of the assessment affected by time and space (**Figure 12**).

Time and space lead to the uncertainty of indicators, resulting in the difference of model evaluation results. Because the average uncertainty of spatial distribution index is so 0.5, which is about 4.26% of the average comprehensive score of the study area,

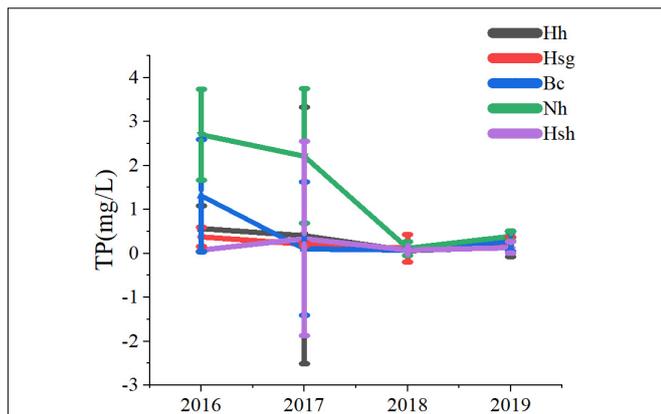


FIGURE 8 | Annual changes of eutrophication in Huangshui wetland. TP (Total Phosphorus), The unit of concentration is mg/L; Hh (Haihu Wetland); Hsg (Huoshagou Wetland); Bc (Beichuan Wetland); Nh (Ninghu Wetland); Hsh (Huangshuihe Wetland).

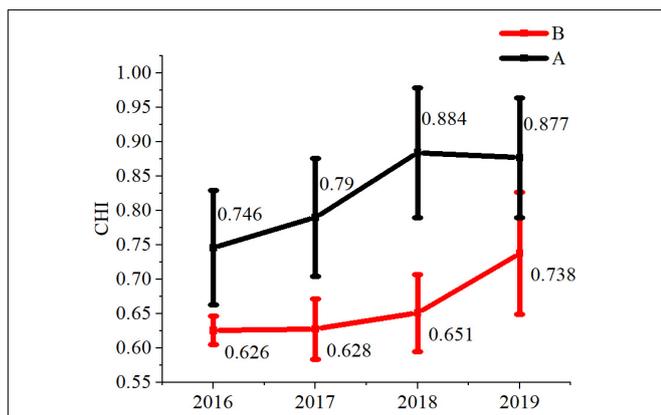


FIGURE 9 | The red trend line indicates the health evaluation results of the ordinary PSR model. The black trend line represents the health evaluation results of the PSR-BP neural network model.

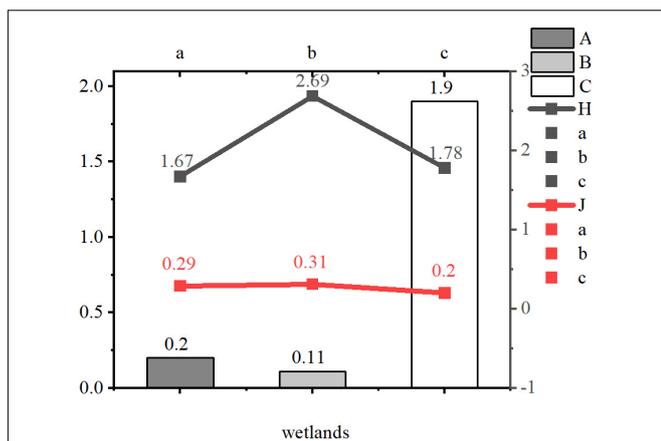


FIGURE 10 | (a): "H" is the Shannon Wiener index of birds in 2019. "J" is the Pielou uniformity index of birds in 2019. "a": Haihu wetland. "b": Beichuan wetland. "c": Ninghu wetland. "A": Increase rate of wild bird species in 2018-2019. "B": Increase rate of waterfowl in 2018-2019. "C": Increase rate of waterfowl in 2018-2019.

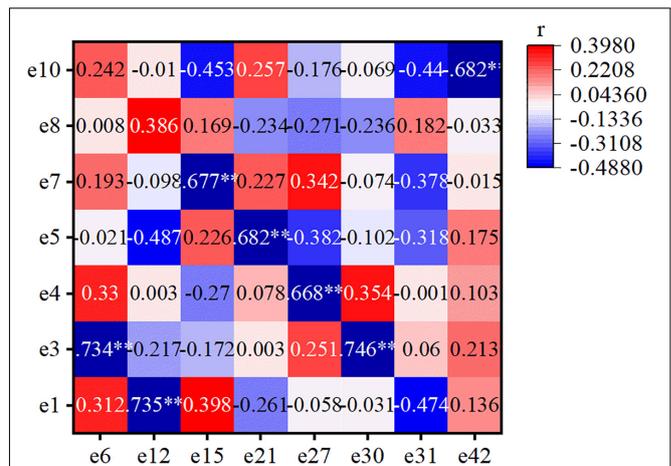


FIGURE 11 | Correlation analysis of the evaluation indicators for the plateau urban national wetland in Huangshui. Population density e1; green coverage rate of the built-up area e3; cumulative area under soil erosion control e4; number of tourists e5; sewage treatment e6; land use intensity e7; sewage discharge e8; ecological environment hydration e10; low temperature e12; wildlife survival rates e15; dissolved oxygen e21; total nitrogen e27; absorb carbon dioxide e30; oxygen release e31; disposition of surrounding population e42.

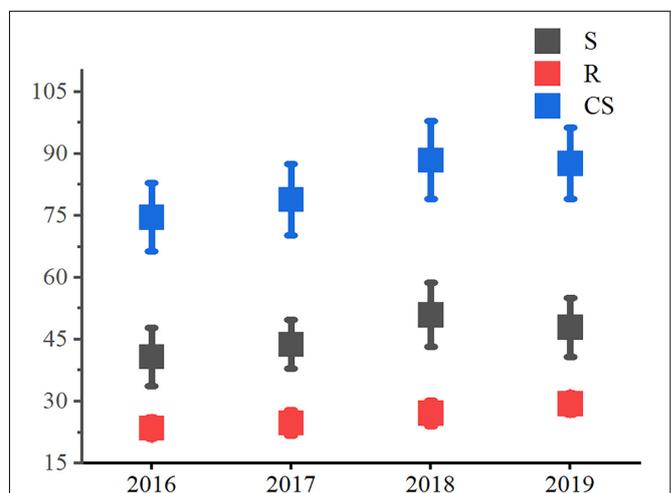


FIGURE 12 | Uncertainty analyses of assessment of four wetlands. "a": Haihu wetland. "b": Huoshagou wetland. "c": Beichuan wetland. "d": Ninghu wetland. "e": Huangshuihe wetland. "S": Average score of state indexes. "R": Average score of response indexes. "Cs": Average score of comprehensive health score.

the average uncertainty of status index (4.48%) > the average uncertainty of response index (2.51%); Under the influence of time change, the average uncertainty is not play of thinking for about 6% of the average comprehensive score of the wetland in the study area. The average uncertainty of state index and response index is 6.94 and 2.83% respectively; the error caused by artificial selection of neural network nodes increases the uncertainty of index weight.

Taking Beichuan as an example, its CRS ranges from 75.64 to 91.11, which is owned by a fairly good level. The pressure

of traffic and population around the spatial distribution increases gradually, and the average uncertainty is 7.73%. The climate change over time has an effect on the wetland evaluation results. Owing to the uncertainty, the uncertainty of different evaluation indicators of wetlands with different temporal and spatial distribution is different. In general, the uncertainty of state indicators is the largest.

CONCLUSION

Given China's fast urbanization and eco-desires under the latest discourse on ecological civilization, the exploration focus of researchers is to find suitable ecological evaluation methods for urban wetlands (Wang, 2020). By combining PSR and BP artificial neural network models, a health evaluation model of plateau urban wetlands was built by using AHP and other methods, and a health evaluation model of plateau urban wetlands including 3 comprehensive indices and 45 evaluation indicators was constructed. The fitting results were of high quality, revealing the weight of the evaluation indicators of plateau urban wetlands and their synergy and trade-off relationship, and finding the evaluation factors that can truly evaluate the health of plateau urban wetlands. We used model to evaluate comprehensive health of wetlands from 2016 to 2019.

- (1). The proposed method selects seven effective evaluation indexes, including the pressure index in PSR model: population density. Status indicators include humidity, eutrophication, carbon dioxide absorption and entertainment. Response indicators include wetland management level, ecological construction and protection investment.
- (2). The evaluation results show that from 2016 to 2019, after taking wetland ecological restoration measures, the interannual comprehensive average score increased from 0.746 (2016) to 0.877 (2019). The overall health index of urban wetlands in the plateau has increased, indicating that ecological restoration has played an active role.
- (3). Compared with the single PSR method, the PRS-BP model selects 8 indicators suitable for evaluating the health of plateau wetlands. Therefore, this model only evaluates 8 evaluation indicators, which is simple and operable. The time span of BP neural network model fitting index data is large. According to the output weight of the model, interference of highly variable indexes is eliminated, and the evaluation result is more accurate and reasonable.”

REFERENCES

- Ahn, C., and Schmidt, S. (2019). Designing wetlands as an essential infrastructural element for urban development in the era of climate change. *Sustainability* 11:1920. doi: 10.3390/su11071920
- Asare, E. A., Assim, Z. B., Wahi, R. B., Tahir, R. B., and Droepenu, E. K. (2021). Application of fuzzy evaluation technique and grey clustering method for water quality assessment of the coastal and estuaries of selected rivers in Sarawak. *Bull. Natl. Res. Centre* 45, 156–167. doi: 10.1186/s42269-021-00616-9
- Asomani-Boateng, R. (2019). Urban wetland planning and management in Ghana: a disappointing implementation. *Wetlands* 39, 251–261. doi: 10.1007/s13157-018-1105-7
- Bian, J. M., Hu, Y. X., Li, Y. S., Ma, Y. X., and Bian, J. (2014). Study on water quality evaluation in the source area of Liaohe River based on BP neural network. *Soil Water Conserv. Res.* 21, 147–151. doi: 10.13869/j.cnki.rswc.2014.01.029
- Bolund, P., and Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecol. Econ.* 29, 293–301. doi: 10.1016/S0921-8009(99)00013-0
- Boyer, T., and Polasky, S. (2004). Valuing urban wetlands: a review of nonmarket valuations studies. *Wetlands* 24, 744–745. doi: 10.1672/0277-52122004

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because none. Requests to access the datasets should be directed to LT, <https://data.cnki.net/area/Yearbook/Single/N2020110002?z=D29>.

ETHICS STATEMENT

The sample collection in this study was approved by the Management Committee of the Huangshui National Constructed Wetland.

AUTHOR CONTRIBUTIONS

LT, XM, and XW wrote the manuscript and performed the statistical analysis. XS, WT, YD, HY, ZD, FX, HZ, and XY contributed to the field and laboratory experiments. All authors contributed model construction, data analysis and manuscript revision.

FUNDING

The study was supported in part by the National Natural Science Foundation of China (Project No. 51669028), "Western Young Scholars" project of the Chinese Academy of Sciences and Qinghai Provincial Key Laboratory of Natural Geography and Environmental Process (2020-zj-y06).

ACKNOWLEDGMENTS

We would appreciate two reviewer's valuable comments on our manuscript. We would also appreciate Xianming Yang, Kai Du, Yanxiang Jin, Xin Jin, and Nana Zhang for their help in field work.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2022.866597/full#supplementary-material>

- Cao, J. F., Ping, J. H., Oumar, S., Jiang, J. Y., Shen, Y. Y., and Qin, L. J. (2006). Application of improved BP neural network in groundwater environmental quality assessment. *Adv. Water Resour. Hydropower Sci. Technol.* 26, 21–23.
- Costanza, R. (1992). Ecological economics: the science and management of sustainability. *Am. J. Agric. Econ.* 7, 170–171.
- Cui, B. S., Yang, Z. F., Li, Y. H., Zhang, K. G., and Zhao, X. S. (2004). Comprehensive protection and development of wetland in urban expansion. *J. Nat. Resour.* 19, 462–471.
- Fang, X. S., Liu, S., Chen, W. Z., and Wu, R. Z. (2021). An effective method for wetland park health assessment: a case study of the Guangdong Xinhui National Wetland Park in the Pearl River Delta, China. *Wetlands* 41:44. doi: 10.1007/s13157-021-01418-5
- Ferreira, N. C., Bonetti, C., and Seiffert, W. Q. (2011). Hydrological and water quality indices as management tools in marine shrimp culture. *Aquaculture* 318, 425–433. doi: 10.1016/j.aquaculture.2011.05.045
- Han, Y., He, F., Chen, Y., Qin, W., Yu, H., and Xu, D. (2021). Quality assessment of protein docking models based on graph neural network. *Front. Bioinform.* 1:693211. doi: 10.3389/fbinf.2021.693211
- Hanbay, D., Turkoglu, I., and Demir, Y. (2008). Prediction of wastewater treatment plant performance based on wavelet packet decomposition and neural networks. *Expert Syst. Appl.* 34, 1038–1043. doi: 10.1016/j.eswa.2006.10.030
- Hines, D. E., Ray, S., and Borrett, S. R. (2018). Uncertainty analyses for ecological network analysis enable stronger inferences. *Environ. Model. Softw.* 101, 117–127. doi: 10.1016/j.envsoft.2017.12.011
- Ho, M., and Richardson, C. J. (2013). A five year study of floristic succession in a restored urban wetland. *Ecol. Eng.* 61, 511–518. doi: 10.1016/j.ecoleng.2013.05.001
- Holland, C. C., Honea, J. E., Gwin, S. E., and Kentula, M. E. (1995). Wetland degradation and loss in the rapidly urbanizing area of Portland, Oregon. *Wetland* 15, 336–345. doi: 10.1007/BF03160888
- Hu, S., Niu, Z., Chen, Y., Li, L., and Zhang, H. (2017). Global Wetlands: potential distribution, wetland loss, and status. *Sci. Total Environ.* 586, 319–327. doi: 10.1016/j.scitotenv.2017.02.001
- Jiao, J. L., Ren, H. L., and Sun, S. Z. (2016). Assessment of surface ship environment adaptability in seaways: a fuzzy comprehensive evaluation method. *Int. J. Naval Archit. Ocean Eng.* 8, 344–359. doi: 10.1016/j.ijnaoe.2016.05.002
- Jiang, T. (2001). Principles of animal ecology. *Acta Ecol. Sin.* 11:1868.
- Jing, B. Z., Wu, J., and Gong, Y. Z. (2020). Valuing wetland ecosystem services based on benefit transfer: a meta-analysis of China wetland studies. *J. Clean. Prod.* 276:122988. doi: 10.1016/j.jclepro.2020.122988
- Jonathan, P. R., Andrew, T. K., Emily, A. S., Victor, H., Chris, N., Ruth, C., et al. (2019). The application of wearable technology to quantify health and wellbeing co-benefits from urban wetlands. *Front. Psychol.* 10:1840. doi: 10.3389/fpsyg.2019.01840
- Kuo, J. T., Hsieh, M. H., Lung, W. S., and She, N. (2007). Using artificial neural network for reservoir eutrophication prediction. *Ecol. Model.* 200, 171–177. doi: 10.1016/j.ecolmodel.2006.06.018
- Lee, S. Y., Dunn, R. J. K., Young, R. A., Connolly, R. M., Dale, P. E. R., Dehayr, R., et al. (2006). Impact of urbanization on coastal wetland structure and function. *Austral Ecol.* 31, 149–163. doi: 10.1111/j.1442-9993.2006.01581.x
- Li, H., Wang, X., Wei, H., Xia, T., Liu, M., and Ai, S. (2022). Geographical distribution and driving meteorological forces of facial expressions of visitors in urban wetland parks in eastern China. *Front. Earth Sci.* 10:781204. doi: 10.3389/feart.2022.781204
- Liu, F., and Lu, J. B. (2021). Ecological engineering approaches to restoring the aquatic biological community of an urban pond ecosystem and its effects on water quality – a case study of the urban Xixi National Wetland Park in China. *Knowl. Manag. Aquat. Ecosyst.* 422:24. doi: 10.1051/kmae/2021024
- Liu, P., Liu, M., Xia, T., Wang, Y., and Wei, H. (2021). Can urban forest settings evoke positive emotion? Evidence on facial expressions and detection of driving factors. *Sustainability* 13:8687. doi: 10.3390/su13168687
- Mao, X. F., and Wei, X. Y. (2015). The spatial and temporal distribution of chlorophyll a and its influencing factors in an eutrophic lake. *Environ. Monitor. China* 31, 65–70. doi: 10.19316/j.issn.1002-6002.2015.06.012
- Mao, X. F., Wei, X. Y., Jin, X., Tao, Y. Q., Zhang, Z. F., Wang, W. Y., et al. (2019). Monitoring urban wetlands restoration in Qinghai Plateau: integrated performance from ecological characters, ecological processes to ecosystem services. *Ecol. Indic.* 101, 623–631. doi: 10.1016/j.ecolind.2019.01.066
- Mao, X. F., Wei, X. Y., Yuan, D. H., Jin, Y., and Jin, X. (2018). An ecological-network-analysis based perspective on the biological control of algal blooms in Ulansuhai Lake, China. *Ecol. Model.* 386, 11–19. doi: 10.1016/j.ecolmodel.2018.07.020
- McInnes, R. J. (2014). Recognising wetland ecosystem services within urban case studies. *Mar. Freshw. Res.* 65, 575–588. doi: 10.1071/MF13006
- Mo, M. H., Wang, X. L., Wu, H. J., Cai, S. M., Zhang, X. Y., and Wang, H. L. (2009). Ecosystem health assessment of Honghu Lake Wetland of China using artificial neural network approach. *Chin. Geograph. Sci.* 19, 349–356. doi: 10.1007/s11769-009-0349-9
- Rheinhardt, R. D., Brinson, M. M., and Paul, M. F. (1997). Applying wetland reference data to functional assessment, mitigation and restoration. *Wetlands* 17, 195–215.
- Robert, J. R., Donagh, H., and Jennifer, J. R. (2021). Integrating artificial urban wetlands into communities: a pathway to carbon zero? *Front. Built Environ.* 7:777383. doi: 10.3389/fbuil.2021.777383
- Stefanak, A. I. (2019). The role of constructed wetlands as green infrastructure for sustainable urban water management. *Sustainability* 11:6981. doi: 10.3390/su11246981
- Sun, W. G., Wang, H. X., and Yu, S. P. (2004). The advance of urban wetland study. *Prog. Geogr.* 23, 94–100.
- Sutton-Grier, A. E., and Sandifer, P. A. (2019). Conservation of wetlands and other coastal ecosystems: a commentary on their value to protect biodiversity, reduce disaster impacts, and promote human health and well-being. *Wetlands* 39, 1295–1302. doi: 10.1007/s13157-018-1039-0
- Wahlroos, O., Valkama, P., Mäkinen, E., Ojala, A., Vasander, H., Väänänen, V. M., et al. (2015). Urban wetland parks in Finland: improving water quality and creating endangered habitats. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* 11, 46–60. doi: 10.1080/21513732.2015.1006681
- Wang, H. X., Sun, G. Y., Gong, H. L., and Yu, S. P. (2006). Characteristics of urban wetland and its construction policies upon the sustainable development strategy in Beijing. *J. Arid Land Resour. Environ.* 20, 94–100.
- Wang, J., Wang, X., Zhang, X. H., Li, H. C., Lei, X. H., Wang, H., et al. (2018). Application of grey clustering method based on improved analytic hierarchy process in water quality evaluation. *MATEC Web Conf.* 246:02004. doi: 10.1051/mateconf/201824602004
- Wang, T. (2020). Wetland governance: contested aspirations and reflexive roles of local professionals toward Worlding cities in tai lake basin. *Front. Environ. Sci.* 8:577357. doi: 10.3389/fenvs.2020.577357
- Wei, H., Ma, B., Hauer, R. J., Liu, C., Chen, X., and He, X. (2020). Relationship between environmental factors and facial expressions of visitors during the urban forest experience. *Urban For. Urban Green.* 53:126699. doi: 10.1016/j.ufug.2020.126699
- Wei, M., Zheng, Z., Bai, X., Lin, J., and Taghizadeh-Hesary, F. (2021). Application of rough set and neural network in water energy utilization. *Front. Energy Res.* 9:604660. doi: 10.3389/fenrg.2021.604660
- Wu, J. M., Xu, D., He, F., He, J., and Wu, Z. B. (2015). Comprehensive evaluation of substrates in vertical-flow constructed wetlands for domestic wastewater treatment. *Water Pract. Technol.* 10, 625–632. doi: 10.2166/wpt.2015.077
- Wu, Y., Mao, X. F., Zhang, Z. F., Tang, W. J., Cao, G. C., Zhou, H. K., et al. (2021). Temporal and spatial characteristics of CO₂ flux in plateau urban wetlands and their influencing factors based on eddy covariance technique. *Water* 13:1176. doi: 10.3390/w13091176
- Wu, Y. C., and Feng, J. W. (2018). Development and application of artificial neural network. *Wirel. Pers. Commun.* 102, 1645–1656. doi: 10.1007/s11277-017-5224-x
- Xia, H. J., Liu, L. S., Bai, J. H., Kong, W. J., Lin, K. X., and Guo, F. (2006). Wetland ecosystem service dynamics in the yellow river estuary under natural and anthropogenic stress in the past 35 years. *Ecol. Eng.* 26, 27–39. doi: 10.1007/s13157-020-01368-4
- Zhang, H. Y., Sun, Y. D., Zhang, W. X., Song, Z. Y., Ding, Z. L., and Zhang, X. Q. (2021). Comprehensive evaluation of the eco-environmental vulnerability in the Yellow River Delta wetland. *Ecol. Indic.* 125:107514. doi: 10.1016/j.ecolind.2021.107514

- Zhang, L. N., Wu, F. P., and Jia, P. (2013). Grey evaluation model based on reformative triangular whitenization weight function and its application in water rights allocation system. *Open Cybernet. Syst. J.* 7, 1–10. doi: 10.2174/1874110X20130521001
- Zhang, M. L., and Yang, W. P. (2012). Fuzzy comprehensive evaluation method applied in the real estate investment risks research. *Phys. Procedia* 24, 1815–1821. doi: 10.1016/j.phpro.2012.02.267
- Zhang, M. W., Jin, H. J., Cai, D. S., and Jiang, C. B. (2010). The comparative study on the ecological sensitivity analysis in Huixian karst wetland, China. *Procedia Environ. Sci.* 2, 386–398. doi: 10.1016/j.proenv.2010.10.043
- Zhou, L. F., and Xu, S. G. (2006). Application of grey clustering method in eutrophication assessment of wetland. *J. Am. Sci.* 2, 53–58.
- Zou, Q., Zhou, J. Z., Zhou, C., Song, L. X., and Guo, J. (2013). Comprehensive flood risk assessment based on set pair analysis-variable fuzzy set model and fuzzy AHP. *Stoch. Environ. Res. Risk Assess.* 27, 525–546. doi: 10.1007/s00477-012-0598-5
- Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
- Publisher's Note:** All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2022 Tong, Mao, Song, Wei, Tang, Deng, Yu, Deng, Xiao, Zhou and Yin. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.