Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 21 | No. 1 | pp. 297-302 | 2022
Original Research Paper
https://doi.org/10.46488/NEPT.2022.v21i01.035
Open Access Journal

Study of Water Quality Pollution Index, Land-Use and Socio-Economic Factors in Yingkou Irrigation District of China Based on Redundancy Analysis

Ji He*, Xiao-Ling Hou* and Wen-chuan Wang*†
*School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou City, Henan Province, 450045, PR China
†Corresponding author: Wen-chuan Wang; wwc_hs@126.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 11-02-2021
Revised: 21-03-2021
Accepted: 14-04-2021

Key Words:
Water quality
Irrigation district
Redundancy analysis
Land-use
Socio-economic factors

ABSTRACT

Water quality in irrigation areas is related to food security and many other national strategies. This study takes China's Yingkou Irrigation District as the research object and analyzes 4 water quality indicators, including NH_4^+-N, TP, DO and COD, from 2017 to 2019 at 3 water quality monitoring points set up in the irrigation area. Simultaneously, a comprehensive pollution index is introduced to evaluate the quality of returned water in the irrigation area. Using Redundancy Analysis (RDA), the correlation between water quality indicators and Land-use and socio-economic indicators are analyzed separately. The results show that the water quality of the Yingkou Irrigation District varies greatly within and between years, and the months with poor water quality are concentrated in autumn and winter. This is mainly related to the geographical location of the irrigation area and the drainage cycle of rice planting. The quality of receding water shows a positive correlation with the water area and a negative correlation with the unused land. The RDA analysis with socio-economic indicators shows that PD and IP are the ones that have a more significant impact on the quality of return water in irrigation areas. The prevention and control of industrial point source pollution, as well as the interception of non-point source pollution in water regions, should be the focus of water pollution prevention and control in irrigation areas.

INTRODUCTION

As the most populous country in the world, China's food security is related to social stability, economic development, and even national security. Irrigation areas are the primary food production areas, especially large-scale irrigation areas where rice is the main crop. Studying the water quality of its irrigation water, accurately evaluating water quality categories, and clarifying the response relationship between water quality and Land-use in irrigation areas are of vital importance for ensuring the country's food security.

The influence of agricultural non-point source pollution on the quality of the water environment has been increasingly significant in recent years. If it is released directly without treatment as one of the main output channels of farmland retreat, it would not only wastewater resources but also have an impact on the water quality of receiving water bodies. Yang et al. (2009) pointed out that the unreasonable application of farmland chemical fertilizers, pesticides, livestock and poultry breeding, and agricultural film residues all produced agricultural pollution to varying degrees, which entered the Yellow River along with runoff or drainage, resulting in deterioration of water quality. Xing et al. (2011) selected 3 typical agricultural irrigation drainage ditches to estimate the amount of non-point source pollutants entering the Yellow River in the Ningxia irrigation area and pointed out that the main reason for the sharp increase in water mineralization in the Ningxia section of the Yellow River is the non-point source of agricultural irrigation. Point source pollution is primarily to blame for the increase in COD levels. Point and non-point source pollution both contribute to the rise in nitrogen pollution concentrations. Yang et al. (2015a) studied the Yinxin ditch and the fifth drainage ditch and found that there is a significant positive correlation between the pollution load of farmland in the two ditches and the amount of returned water.

At the same time, there are many methods for evaluating surface water quality (Wang et al. 2019, Zhou et al. 2016). There are mainly analytic hierarchy processes and fuzzy evaluation methods (Zhang 2019). Others include the gray evaluation method and the support vector machine classification method (Chen et al. 2013). Baghapour et al. (2013) used the pollution index approach to assess the water quality of an irrigation area in Canada. In comparison to other water quality evaluation methods, it can authentically and thoroughly depict water quality by taking into account the diversity of water quality indicators and combining them with water quality requirements through the weighted average procedure.

Many scholars have studied the relationship between Land-use types and farmland withdrawal from different perspectives. The intensity of the land use/cover type of the watershed and the different scales from the river bank also have an important impact on various water quality indicators in the water body (Wang et al. 2015). In addition, studies have shown that the social economy of the basin also has an individual impact on the quality of the water environment (Wang et al. 2018). Land-use types can reveal the status quo of regional socio-economic development to a certain extent (Yang 2004, Yang et al. 2015b), and affect the spatial changes of population settlement and mobility (Zhao et al. 2018). At the same time, social development, economic structure, population, and residents' lifestyles also affect the spatial changes of regional land-use types (Seto & Fragkias 2005, Yang 2015, Li et al. 2017b). This circular effect always affects the water environment quality of the basin in the process of social development (Wang et al. 2012, Zhao et al. 2013, Li et al. 2017a).

The Daliao River is the principal water source for the Yingkou Irrigation District in Liaoning Province, China, and two separate irrigation and drainage systems have been established within the irrigation area. The irrigation area adopts extensive irrigation methods, and the controlled irrigation area is large, the drainage and other facilities are low, and the field irrigation water utilization coefficient is low. There is a large amount of irrigation water in the irrigation area to replenish groundwater or drain into the trench by way of serious leakage. The excessive problem is more serious, which is not conducive to the rational use of water resources. As the retreating water enters the river, there are also farmland nutrients and agricultural chemicals, which not only affect the water quality of the river, but the retreat from the irrigation area will eventually enter the Daliao River, which will also have a certain impact on the water environment of the Daliao River. This study takes Yingkou Irrigation District as the research object, uses the comprehensive pollutant index method to evaluate the water quality, and analyzes the intra-year and inter-annual changes in water quality. Simultaneously, the link between Land-use and socio-economic parameters in the irrigation region and the quality of returned water was investigated using RDA analysis. It is planned to serve as a foundation for Land-use optimization and water pollution prevention and management in the Yingkou Irrigation District.

MATERIALS AND METHODS

Study Area

Yingkou Irrigation District is located at the southern end of the Central Plains of Liaoning, China, on the left bank of the lowest reaches of the Daliao River. It involves Zhanqian, Laobian, and Dashiqiao City in Yingkou City, with a total land area of 91246 hectares (Fig. 1). The irrigation area is flat, with many river networks and depressions. The terrain is high in the northeast and low in the southwest, and the ground elevation is mostly between 2.0m and 6.0m.

The study area has a monsoon climate with cold and dry winters, windy and less rainy in spring, concentrated hot rainfall in summer, and long cool sunshine in autumn. The annual average temperature is 9.1°, the monthly average temperature is 27.1° in July, and the lowest in January is -15.0°. The average yearly precipitation is 650.5 mm. The precipitation is unevenly distributed throughout the year, and the main period (June to September) accounts for about 71.9% of the annual rainfall.

The western and southern parts of the study area developed into irrigation areas after long-term river alluvium and human activities. Most plots of topsoil salt are separated into extremely mild and moderate after decades of rice farming improvements, and there are fewer salinized soils above moderate. During the flood season, the groundwater level in the irrigation region is rather high, with a burial depth of 0.7-1.0 m and it being close to the surface.

Data Source

Landuse data: The Landsat satellite remote sensing image (spatial resolution 30 m) in September 2018 was used to cut out the study area corresponding to the Yingkou Irrigation Area and perform related pre-processing image enhancement in ArcGIS and ENVI software. Combining field surveys, Google Earth software, and image resolution characteristics, remote sensing images are interpreted and classified based on the Recognition software supervised classification method. The Land-use categorization system is based on the Chinese Academy of Sciences' land resources classification system, which covers six types of land use: forest land, grassland, agricultural land, construction land, water area, and unused land.

Water quality monitoring: The local environmental protection bureau set up water quality sampling points at the section of the main canal of the Laodong River into the Daliao River estuary. The location of the monitoring section is shown in Fig. 1. The water quality monitoring period is from January 2017 to December 2019. The monitoring frequency is once a month. The measured water quality indicators include NH_4^+-N TP, DO, and COD.

Research Methods

Pollution index evaluation: The pollution index evaluation method is a relatively common method for evaluating river pollution levels at home and abroad. The evaluation indicators involve various organic pollutants and inorganic pollutants, such as nitrogen, phosphorus, and COD. The water quality evaluation in this paper adopts the average pollution index method, which is:

$$PI = \frac{1}{n}\sum_{i=1}^{n} c_i/S_i$$

Where PI is the average pollution index, n is the number of pollution factors participating in the evaluation, i is the pollution factor, c_i is the measured content of the pollution factor i, and S_i is the standard evaluation value of the pollution factor i. Refer to the surface water environmental quality standard (GB 3838- 2002) and comprehensively determine the water quality standards of the water function zone where the river section is located. (Because the more extensive the dissolved oxygen value, the smaller the pollution, so this index adopts its reciprocal value).

RDA Analysis

Redundancy analysis (RDA) is a sorting method developed based on correspondence analysis. It is a restricted ranking. It can be found by comparing principal component analysis. Redundancy analysis is constrained principal component analysis, which combines correspondence analysis and multiple regression analysis. Each step of the calculation is a regression with environmental factors, also known as multiple direct gradient analysis.

In this study, the proportion of Land-use types and socio-economic parameters were used as environmental factors, and the above indicators were used to reflect the relationship between water quality parameters. The RDA analysis of this research is realized by CANOCO 5.0 software.

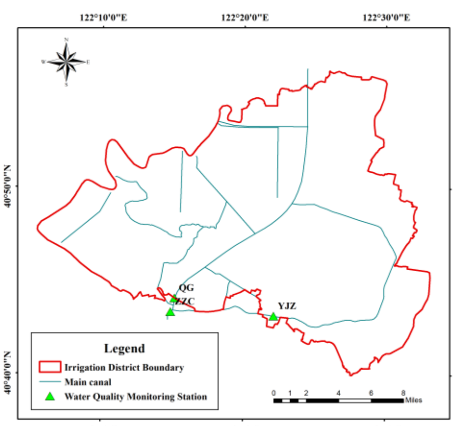

Fig.1: Geographic location of the study area.

RESULTS AND DISCUSSION

Water Quality Change Trend

This study analyzed the four water quality indicators of NH_4^+-N, TP, DO, and COD monitored by three water quality monitoring stations in Yingkou Irrigation District from 2017 to 2019, as well as the calculated PI. The inter-annual analysis of each parameter is shown in Table 1, and the multi-year statistical data is shown in Fig. 2.

Through analysis, it can be seen that various indicators have changed significantly during the year. For NH_4^+-N, the maximum value appeared in February 2018, which was 26 mg.L^{-1}, and the minimum value appeared in June 2017, which was only 0.12 mg.L^{-1}. The main reason for this phenomenon may be that in February, the entire river in the study area was frozen, the fluidity of the water body was weak, and the dilution effect of the water body on the pollutants was not strong, which caused the appearance of the maximum value. In June, the study area was in the flood season. At this time, the water in the study area was abundant. At the same time, in terms of irrigation, the rice was in the growth period and the paddy field drainage was less during this period. The above reasons caused the lowest ammonia nitrogen concentration in the month.

For TP, the inter-annual and intra-annual changes are relatively small, the maximum occurs in April, at 0.83 mg.L^{-1}, and the minimum occurs in June, at 0.11 mg.L^{-1}. The main reason for the peak value in April maybe because the paddy

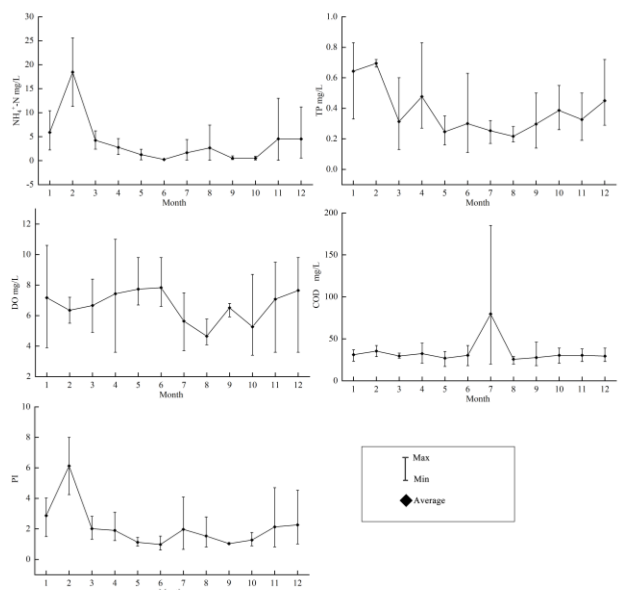

Fig. 2: Changes in water quality parameters during the year.

Table 1: Interannual statistical analysis of water quality parameters.

YEAR		NH_4^+-N	TP	DO	COD	PI
2017	AVERAGE	5.74	0.51	5.10	45.36	2.90
	MIN	0.12	0.16	3.40	18.00	1.05
	MAX	13.00	0.83	7.00	185.00	4.70
	STDEV	4.77	0.23	1.46	44.70	1.39
2018	AVERAGE	3.80	0.35	7.48	32.08	1.97
	MIN	0.16	0.14	3.90	21.00	0.80
	MAX	25.60	0.83	9.80	46.00	8.00
	STDEV	7.14	0.23	2.14	7.28	2.04
2019	AVERAGE	0.79	0.26	7.52	23.73	1.00
	MIN	0.08	0.11	3.70	17.00	0.61
	MAX	2.40	0.35	11.00	33.00	1.50
	STDEV	0.85	0.09	2.38	6.05	0.28

field in the irrigation area just ended during this period. Phosphorus-containing pollutants adhered to the suspended solids such as silt and entered the river with the receding water from the farmland. Rise. The reason for the minimum value is the same as NH_4^+-N.

The largest month of DO appearance is April 2019. The emergence of the maximum value is accompanied by the spring floods and the receding of farmland during the same period. The increase of surface runoff greatly increases the water volume in the river, and the water flow is sufficient, which significantly increases the dissolved oxygen content in the water body. The DO content was the lowest in October 2017. During this season, a certain degree of freezing has occurred in the rivers in the study area, the exchange between water and air has weakened, and the water has low oxygen content.

COD index time variability is large. The maximum value (185 $mg.L^{-1}$) is 10.9 times the minimum value (17 $mg.L^{-1}$). The main reason for the large deviation of COD may be due to the different levels of pesticides applied in the irrigation areas at different times, which caused large differences in COD content. At the same time, due to the continuous accumulation of organic pollutants, some areas, especially downstream rivers, will be more affected by organic pollutants.

PI can comprehensively reflect the pollutant situation. As can be seen in Fig. 3, there is a big difference in PI during the year, with the largest average value occurring in February and the smallest value occurring in June. The freezing of rivers in February weakened the dilution of pollutants from external water sources, resulting in higher pollutant concentrations during this period. During the flood season in June, there was more precipitation and less drainage from the rice fields, which dilutes the concentration of pollutants and does not increase the number of new pollutants in the river. This is the main reason for the small pollutant index during this period.

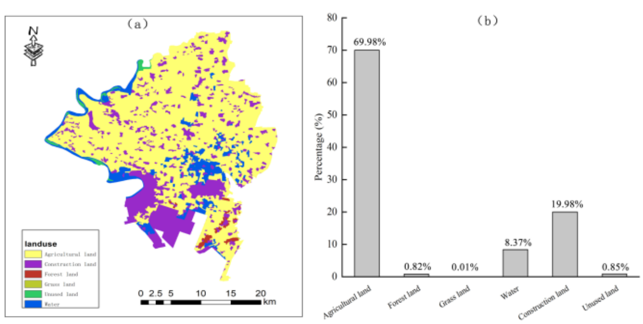

Fig. 3: The area proportion of different land-use types in Yingkou Irrigation Area

The Impact of Land-use on Water Quality

Land-use composition of yingkou irrigation district: The spatial analysis software of ArcGIS 10.2 is used to superimpose analysis and calculation of the boundary and Land-use data of the irrigation area, and the distribution of each land-use type in the irrigation area is shown in Fig. 3.

It can be seen from the figure that the primary Land-use type in the irrigation area is agricultural land, accounting for 69.98%, followed by construction land (19.98%), and the remaining land is water area (8.37%) and unused land (0.85%), woodland (0.82%), and grassland has the smallest area. As the irrigation area is mainly planted with rice and corn, the area of agricultural land is the largest. The southern part of the irrigation area is currently mixed with major industrial and mining enterprises in the main urban area, so the construction land area is also relatively large. A large number of fish ponds and dense channels distributed in the irrigation area are the main reasons for the large water area.

Correlation analysis between the quality of returning water and land use: It can be seen from Fig. 4 that DO has a negative correlation with water surface area and a positive correlation with unused land. This may be mainly because the unused land in the irrigation area contains less organic matter, so there are fewer oxygen-consuming microorganisms, which makes the dissolved oxygen content in the water higher. The NH4-N, TP, COD, and PI indexes of Yingkou Irrigation District all show a positive correlation with water area and a negative correlation with unused land. This may be because the receding water in the Yingkou Irrigation District is the receding water of the rice fields. The receding water from the fields entrained pollutants into the water body, thus showing a positive correlation with the water area.

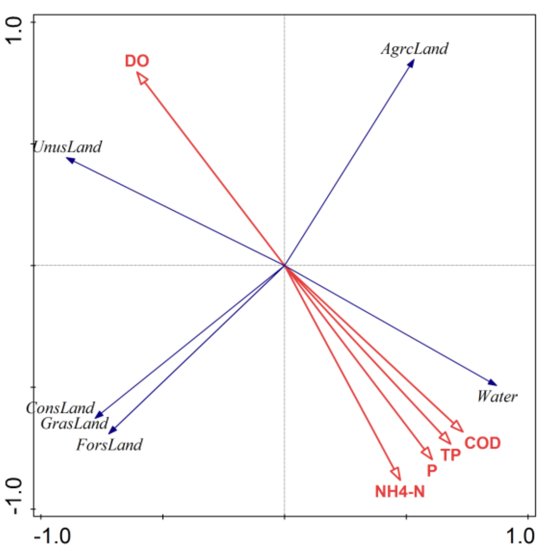

Fig. 4: Correlation between water quality indicators and Land-use types.

The Impact of Socio-Economic Indicators on Water Quality

This study selects four indicators, including population density (PD), agricultural production value (AP), industrial production value (IP), and service industry production value (SIP) as social-economic factors, to evaluate the correlation between them and water quality indicators. It can be seen from Fig. 5 that, except for the dissolved oxygen index, other indicators, including the comprehensive pollution index, show a positive correlation with the GDP of the secondary industry. DO shows a positive correlation between PD and AP. The main reason may be that some industries in the Yingkou Irrigation District currently do not have sewage interception pipes, and the direct discharge of sewage has caused the degradation of water quality. In pollution prevention and control, attention should be paid to the impact of industrial point source pollution on water quality.

In addition to the above-mentioned impact analysis, attention should also be paid to controlling drainage in Yingkou Irrigation District. By controlling the drainage to regulate and control the return of water in the irrigation area, the field drainage and the output of pollutants can be effectively reduced (Skaggs et al. 1994, Wesstrom et al. 2001). As a water-deficient area, the Yingkou Irrigation District has huge potential for reuse. Therefore, in future research, we must consider the combination of project operation mode

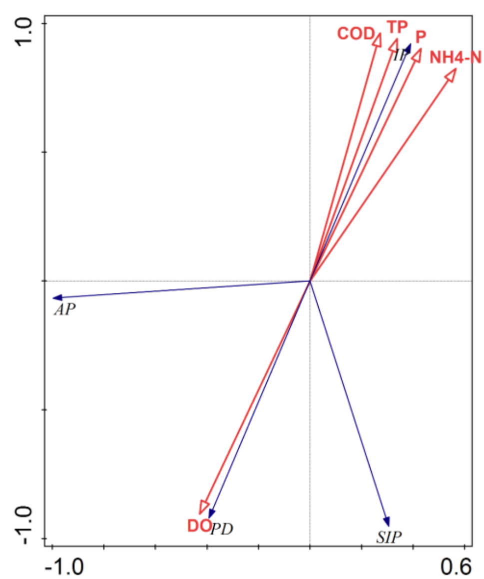

Fig. 5: Correlation between water quality indicators and socio-economic indicators.

and irrigation management measures to jointly promote the construction of the irrigation area.

CONCLUSIONS

This paper introduces the comprehensive pollution index and analyzes the time changes of the pollution index and the water quality index of Yingkou Irrigation District. At the same time, using the method of RDA analysis, the correlation between the quality of returning water and Land-use and socio-economic indicators are analyzed, and the main conclusions are as follows:

(1) The pollutant indicators of the Yingkou Irrigation District show significant variability during and interannual. The extreme values of indicators are mainly concentrated in autumn and winter. The possible reason is that the particular geographical and meteorological conditions of the Yingkou Irrigation District have weakened water flow. Decrease and cause deterioration of water quality. The fall is mainly because the backwater from farmland was discharged into river water bodies during this period, which resulted in poor water quality during this period. Pollution prevention and control should pay enough attention to these two periods.

(2) The ammonia nitrogen, total phosphorus, COD, and PI indexes of Yingkou Irrigation District all show a positive correlation with water area and a negative correlation with unused land. Water quality pollution indicators indicate a positive link with a water area as backwater from paddy fields increases. To limit the number of contaminants entering the river, measures such as planting buffer zones around the waterways can be explored.

(3) The RDA analysis of water quality pollutant indicators and socio-economic indicators shows that pollutant indicators show a positive correlation with the secondary industry but show a negative correlation with population density and gross agricultural production. The next step is to strengthen industrial power pollution treatment and adopt measures such as interception and pipes to reduce the amount of pollution.

REFERENCES

Baghapour, M.A., Nasseri, S. and Djahed, B. 2013. Evaluation of Shiraz wastewater treatment plant effluent quality for agricultural irrigation by Canadian Water Quality Index (CWQI). Ir. J. Environ. Health Sci. Eng., 10: 1-9.

Chen, X., Qiu, L. and Huang, Z. 2013. Application of least square support vector machine in water quality assessment of Taihu Lake Basin. J. of Hydroecol., 34: 16-21.

Li, L., Zhang, Y., Tang, C., Zheng, L., Meng, W., Lu, S. and Dun, Y. 2017a. Modeling of water quality response to land-use patterns in Taizi river basin based on partial least squares. Environ. Sci., 38: 1376-1383.

Li, S., Zhou, J. and Wang, J. 2017b. Spatio-temporal LUCC and driving force in Fuxian Lake watershed from 1974 to 2014. Remote Sens. Land Resour., 29: 132-139.

Seto, K.C. and Fragkias, M. 2005. Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics. Landsc.Ecol., 20: 871-888.

Skaggs, R.W., Brevé, M.A. and Gilliam, J. W. 1994. Hydrologic and water quality impacts of agricultural drainage*. Crit. Rev. Environ. Sci. Technol., 24: 1-32.

Wang, J., Ma, K., Zhang, Y. and Tang, R. 2012. Impacts of Land-use and socioeconomic activity on river water quality. Acta Sci. Circum., 32: 57-65.

Wang, P., Qi, S. and Chen, B. 2015. Influence of Land-use on river water quality in the Ganjiang basin. Acta Ecol. Sin., 35: 4326-4337.

Wang, Q., Wang, S.X., Fan, Z.P. and Li, F.Y. 2018. Impacts of Land-use and socioeconomic activity on spatial variation of water quality in the upper area of Dahuofang Reservoir [in chinese]. Ecol.Sci., 37: 153-161.

Wang, Z., Zhu, S., Liu, Y. and Wang, F. 2019. Comparative application of different water quality evaluation methods in the downstream section of Luanhe River. Water Sav. Irrig., 290: 72-76+81.

Wesstrom, I., Messing, I., Linner, H. and Lindstrom, J. 2001. Controlled drainage -- effects on drain outflow and water quality. Agric. Water Manag., 47: 53.

Xing, J., Qi, X., Huang, Z., Fan, X. and Zhu, D. 2011. The application of the grey clustering method for evaluating the subsiding water quality from cropland in the irrigation area of the Yellow River. J. Irrig. Drain., 11: 74-77.

Yang, G. 2004. Land-use and land cover change and regional economic development: The revelation of the change in cropland area in the Yangtze River Delta during the Past 50 years. J. Geogr. Sci., A: 41-46.

Yang, L., Wang, Ruan, S. and Guan, X. 2015a. Evolution of drain-based research of irrigation return flow pollution in Yinbei irrigation area. Chin. J. Eco-Agric., 23: 1580-1587.

Yang, R. 2015. Spatiotemporal change and driving forces of urban landscape pattern in Beijing. Acta Ecol. Sin., 35: 4357-4366.

Yang, R., Liu, Y. and Long, H. 2015b. The study on non-agricultural transformation co-evolution characteristics of "population-land-industry": A case study of the Bohai Rim in China. Geogr. Res., 34: 475-486.

Yang, S., Zhang, A., Yang, Z. and Yang, S. 2009. Agricultural non-point source pollution in Ningxia irrigation district and preliminary study of load estimation methods. Sci. Agric. Sin., 42: 3947-3955.

Zhang, X. 2019. Application of fuzzy comprehensive evaluation in comprehensive evaluation of water. Environ. Qual. Sci. Technol. Eco. Guide, 27: 124-124.

Zhao, M., Liu, S. and Qi, W. 2018. Spatial identification and scale effects of floating population agglomerations at the community scale： A case study of Beijing. Geogr. Res., 37: 1208-1222.

Zhao, W., Lin, J., Wang, S., Liu, J., Chen, Z. and Kou, W. 2013. Influence of human activities on groundwater environment based on coefficient variation method environmental. Science, 34: 1277-1283.

Zhou, M., Li, W. and Yi, L. 2016. Characteristics and comparison of four water quality evaluation methods. Environ. Sci. Manag., 41: 173-177.