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# Correlation Analysis Between the Water Quality and Land Use Composition in Chaobai River Basin

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## ABSTRACT

Under the influence of global climate change and intense human activities, the world is facing water issue and crisis in varying extent. It is considered to be strategically important to study the relation between land-use change and water environment of the only surface water source of Beijing (a city facing severe water shortage). In this article, the quantitative relation between land-use structure and water environment quality of Chaobai River Basin was discussed. GIS spatial analysis function and Markov transition matrix were used to calculate the composition and changes of land use. Meanwhile the correlation between land-use structure and water quality index was analysed by means of correlation analysis, redundancy analysis (RDA) and other mathematical statistics. The land-use impact on water quality was also investigated. The result indicated that the main means of land use in Chaobai River Basin were forest land, farmland, construction land and waters. The major shifted land during 1995 and 2005 was farmland while during 2005 and 2015 was forest land. The indexes of water quality were deeply influenced by the means of land use, of which the deterioration of water quality was significantly affected by construction land. Water quality could be drastically improved by the spatial distribution of forest land, which was especially sensitive to ammonia and potassium permanganate index. The correlation between farmland area variation and water quality was not remarkable. RDA proved the effect of the land-use forms on water environment of Chao River and Bai River in different years. The results could be used to provide a scientific basis for the land optimization and water pollution control of Chaobai River Basin, as well as guide the policy decision of space development and water environment protection of Chaobai River Basin.

## INTRODUCTION

Land use and water pollutant concentrations are significantly correlated (Brezonik 2002. Donohue 2006, Liang 2013). Among them, urban and agricultural land and water pollutant concentrations are significantly positively correlated with forest land, while grassland and other land-use forms and concentrations of pollutants were negatively correlated (Moreno 2006, Tong 2002). On scale, water quality pollution is influenced by using forms and spatial distribution of land (Rhodes 2001, Schoonover 2006, Hwang 2007). In natural or semi-natural areas, due to the similarities of land-use characteristics (use forms and spatial distribution of land), the correlation between land-use forms and water quality is reflected by a number of catchment units of a comprehensive analysis on basin scale (Deng 2012). In the context of China's strong control and governance on point source pollution, urban and rural non-point source pollution of water environment management under the influence of land-use / cover change has become the focus of the study.

Currently the study of land-use effects on water environment mainly includes two aspects: water volume and quality modelling based on different land-use forms (Beasley 1980, Young 1989) and the study of spatial coupling relation between land-use patterns and water quality (Yue 2006). Due to the limited knowledge of transport process and mechanism of nutrients in the soil and in the soil and water interface, the model is mainly used for the estimates of point source pollution load or nutrient transport flux of rivers (Jiang 2014, Chen 2015). Both the numerical accuracy and spatial precision of concentration simulation of water quality can not satisfy the actual application requirements. So the researches on the quantitative relation between land-use structure and water quality index is favoured by researchers at home and abroad in the aspect of water environment management. In these researches the main questions are focused on the sensitivity of water quality changes to land- use/ land-cover forms (Versace 2008, Zampella 2007) and land-use/land-cover impacts on water quality in the aspects of scale and distance effect (Mehaffey

2005, King 2005). Usually, GIS spatial analysis module combined with statistical methods is used to build regression model between land-use patterns and indicators of water quality (Yin 2005), and thus correlation between the two and scale effect can be analysed quantitatively.

Taking Chaobai River Basin as an example, the spatial and temporal changes of water quality and the manner and extent of land-use impacts on water quality were discussed in this paper by means of mathematical statistics with the data of water quality monitoring and remote sensing interpretation of land use. Furthermore, the effects of land-use structure on water environmental impact was examined with RAD method .The results were put forward to provide references to the relation between land use and water quality as well as provide scientific basis for policy decisions on space development and water environment protection in Chaobai River Basin.

## MATERIALS AND METHODS

**Study area:** Chaobai River Basin, located in the North China Plain (from 115°25' E to117°45' E and 39°10' N to 41° 40' N) was department of the Haihe River Basin. It originated in the northern Yanshan Mountains, flowed through three provinces (Hebei, Beijing and Tianjin) and finally together with the Yongding River flowed into Bohai Sea in Beitang of Tianjin. Chaobai River Basin was divided in two major tributaries in the upstream-Chao River and Bai River, which converge into Miyun Reservoir in the downstream and form Chaobai (Fig. 1).

**Land use in Chaobai River Basin**: Taking into account of the availability and quality of the image, Landsat TM / ETM remote sensing images in 1995, 2005 and 2015 were used in this study for the area (Fig. 2, Fig. 4). The land-use forms were divided into four categories on request: forest land, farmland, construction land and waters. Supported by ARCGIS software, overlay analysis of land-form maps during adjacent periods was performed to obtain the comparisons of area changes and change ranges of three different land-use as well as establish the state transition matrix (Lippe 1985, Liu 2015).

**Water quality of Chaobai River basin**: The water quality data collected and tested at the beginning of every month annually was selected in the storage section of Chao River and Bai River in five years (1995, 2000, 2005, 2010 and 2015) according to data match. Taking the main pollution factors and related research of water environment in, total nitrogen (TN), total phosphorus (TP), ammonia nitrogen ($NH_3$-N), potassium permanganate index ($COD_{Mn}$) and dissolved oxygen (DO) were selected as the key water quality indicators (Table 1).

**Redundancy analysis**: Redundancy analysis (RDA) is an analysis method of direct gradient sequencing to statisti-


Fig. 1: Location map of Chaobai river watershed.

Table 1: Statistics of water quality of Chaobai River Basin.

| Water quality (mg/L) | Year | Specimen | Chao River Maximum | Chao River Minimum | Chao River Average | Bai River Maximum | Bai River Minimum | Bai River Average |
|---|---|---|---|---|---|---|---|---|
| TN | 1995 | 12 | 6.17 | 1.10 | 2.89 | 1.91 | 0.10 | 1.16 |
| | 2000 | 12 | 7.17 | 0.33 | 2.32 | 2.58 | 0.15 | 1.05 |
| | 2005 | 12 | 5.94 | 3.78 | 4.91 | 3.10 | 0.75 | 1.81 |
| | 2010 | 12 | 5.21 | 2.35 | 4.10 | 2.94 | 0.47 | 1.82 |
| | 2015 | 12 | 6.42 | 3.80 | 5.22 | 2.84 | 0.53 | 2.20 |
| TP | 1995 | 12 | 0.110 | 0.01 | 0.024 | 0.060 | 0.01 | 0.016 |
| | 2000 | 12 | 0.090 | 0.020 | 0.029 | 0.030 | 0.010 | 0.016 |
| | 2005 | 12 | 0.190 | 0.010 | 0.045 | 0.210 | 0.010 | 0.078 |
| | 2010 | 12 | 0.190 | 0.030 | 0.078 | 0.160 | 0.010 | 0.049 |
| | 2015 | 12 | 0.140 | 0.010 | 0.033 | 0.080 | 0.010 | 0.024 |
| $NH_3$-N | 1995 | 12 | 1.80 | 0.04 | 0.28 | 0.16 | 0.06 | 0.10 |
| | 2000 | 12 | 0.92 | 0.02 | 0.23 | 0.28 | 0.02 | 0.09 |
| | 2005 | 12 | 0.81 | 0.07 | 0.28 | 0.76 | 0.02 | 0.32 |
| | 2010 | 12 | 0.55 | 0.02 | 0.26 | 0.47 | 0.07 | 0.24 |
| | 2015 | 12 | 0.60 | 0.06 | 0.20 | 1.25 | 0.06 | 0.23 |
| $COD_{Mn}$ | 1995 | 12 | 1.4 | 0.4 | 0.9 | 3.7 | 1.7 | 2.4 |
| | 2000 | 12 | 4.5 | 0.1 | 1.8 | 4.1 | 1.0 | 2.5 |
| | 2005 | 12 | 4.5 | 1.2 | 2.9 | 4.4 | 1.5 | 2.8 |
| | 2010 | 12 | 1.9 | 0.5 | 1.5 | 3.1 | 0.8 | 1.9 |
| | 2015 | 12 | 2.1 | 0.7 | 1.7 | 2.3 | 0.8 | 1.6 |
| DO | 1995 | 12 | 12.8 | 7.6 | 10.2 | 13.5 | 9.5 | 12.0 |
| | 2000 | 12 | 14.0 | 7.8 | 11.3 | 14.0 | 7.8 | 10.4 |
| | 2005 | 12 | 13.0 | 7.8 | 10.5 | 13.0 | 6.4 | 9.2 |
| | 2010 | 12 | 13.2 | 7.8 | 10.1 | 13.1 | 7.2 | 9.4 |
| | 2015 | 12 | 11.4 | 7.4 | 9.9 | 13.4 | 6.7 | 10.3 |

cally evaluate relation between one or a set of multivariate with another set of variables. It is often used for ecological research revealing the relationship between species and the environmental factors of their life. While in this study it was used to analyse the relation between water quality index and land use. RDA can be able to independently maintain the contribution rates of various environmental variables (land use) on water quality changes and is effective on a number of explanatory variables for statistical tests as well as determine the minimum variable groups which are with the greatest explanatory power to changes of variables. The two-dimensional visual map of RDA visually shows the relation between water quality parameters and forms and composition of land-use.

First, with water quality index of monitoring sites regarded as species variables (response variables) and the proportion of land-use forms as environment variables (explanatory variables), under the help of WCanolmp, environmental data and species data would be saved in the format that could be used by Canoco software. Then water quality parameters would be examined in the way of trends correspondence analysis (DCA). According to the length of the gradient, the sorting model (RDA, CCA, DCA) would be defined and analysed based on CANOCO for Windows4.5 (Zhang 2014). The results could be generated in Canodraw for Windows in the forms of sorting map, which would be interpreted.

In the sorted figure, the angle between species arrow (quality parameters) and environmental arrow (the proportion of land-use form) is used to determine the way environmental factors act on species. If the angle between environment arrow and species arrows is less than 90 degrees, the correlation between the two is positive, or concentration (or abundance) of species factor will increase with the increase of environmental factors. If the angle is more than 90 degrees, the correlation between the two is negative, or concentration (or abundance) of species factor will increase with the increase of environmental factors. If the angle is 90 degrees, it indicates that the species factors and environmental factors are completely vertical, or uncorrelated. Also in the sorted figure, the length of environmental arrow (land use) shows the impact of environmental factors (land use) on species factors (water). The longer the environmental arrow is, the higher the degree of the impact is.

## RESULTS

**Basic structure and changes of land-use:** As can be seen from Table 2, forest land was the main land-use form in

Table 2: Area statistics of different land use forms in Chaobai River basin.

| Land-useforms | 1995 | | 2010 | | 2015 | |
|---|---|---|---|---|---|---|
| | Area/km$^2$ | Percentage | Area/km$^2$ | Percentage | Area/km$^2$ | Percentage |
| Forest land | 12162 | 79.07 | 12861 | 83.62 | 12659 | 82.31 |
| farmland | 2659 | 17.29 | 2020 | 13.13 | 2332 | 15.16 |
| Construction land | 57 | 0.37 | 76 | 0.49 | 56 | 0.36 |
| Water area | 482 | 3.27 | 410 | 2.76 | 325 | 2.17 |

Table 3: Transition of land use changes from 1995 to 2005 in Chaobai River Basin hm$^2$.

| 2005/1995 | Farm land | Forest land | Water | Construction land | Total |
|---|---|---|---|---|---|
| Farmland | 166100.04 | 64926.02 | 855.96 | 2974.58 | 234856.6 |
| Forest land | 5928.73 | 901802.03 | 381.08 | 247.22 | 908359.06 |
| Water area | 5218.17 | 2887.31 | 39394.13 | 82.72 | 47582.33 |
| Construction land | 788.95 | 482.43 | 56.94 | 4161.13 | 5489.45 |
| Total | 178035.89 | 970097.79 | 40688.11 | 7465.65 | 1196287.44 |

Table 4: Transition matrix of land use changes from 2005 to 2015 in Chaobai River basin hm$^2$.

| 2005/2015 | Farmland | Forest land | Water | Construction land | Total |
|---|---|---|---|---|---|
| Farmland | 199478.60 | 1477.39 | 344.73 | 68.14 | 201368.86 |
| Forest land | 19605.04 | 1020877.00 | 1648.71 | 1526.17 | 1043656.92 |
| Water area | 1079.15 | 9300.63 | 29835.15 | 80.49 | 40295.42 |
| Construction land | 1546.16 | 2940.88 | 139.23 | 2511.15 | 7137.42 |
| Total | 221708.95 | 1034595.9 | 31967.82 | 4185.95 | 1292458.62 |

2015, of which the area was 12659 km$^2$, accounting for 82.31% of the total basin area. Farmland was following with an area of 2332 km$^2$, accounting for 15.16%. The smallest was construction land with an area of 56 km$^2$, accounting for 0.36%.

Judging from the changes of land-use forms from 1995 to 2015, with the progress of urbanization, the interference of human activities on nature was gradually increasing. The areas of farmland, construction land, forest land and other were significantly changed. Forest land took the main part in the basin, followed by farmland and construction land.

Farmland area in Chaobai River was 2659 km$^2$ in 1995, accounting for 17.29% of the total basin area. While in 2005 and 2015, farmland area was 2020 km$^2$ and 2332 km$^2$ respectively, accounting for 13.13% and 15.16%. Construction land area in 1995 was 57 km$^2$. From 1995 to 2005, farmland area increased rapidly by the percentage of 33.3%. And then construction land area reduced to 56 km$^2$.

Waters area in the study was gradually reduced during the period. Compared with the area in 1995, those in 2005 and 2015 decreased 71 km$^2$ (3.27%) and 157 km$^2$ (2.17)% respectively.

During 1995 and 2005, the features of land-use forms in Chaobai River were as follows (Table 3): transition of farmland area took the main part, transformed into forest land, construction land and waters with the ratio 24.41%, 1.12% and 0.32 % respectively. The transition of forest land accounted for only 3.27%, of which 2.55% and 0.64% of the area were transformed into reducing land and farmland. The ratios of waters transformed into cultivated land, forest and construction land were 10.83%, 5.99% and 0.17% respectively. The transition of construction land area accounted for 26.56%, 13.92% of which of the area was converted to farmland and 8.51% to forest land.

During 2005 and 2015, the features of land-use forms in Chaobai River were as follows (Table 4): transition of farmland area took a small part with the ratio 1.2% , mainly converting into forest land and waters. The transition of forest land accounted for only 0.30%, of which 0.11% of the area was converted into farmland and water area. The ratios of waters transformed into cultivated land, forest and construction land were 8.18%, 3.04% and 0.27%. The change of construction land was extremely small, only 0.92%, 0.74% of which was converted into farmland.

**Correlation analysis of land-use composition and water quality:** Based on five years' annual water quality indicators of the sections of Chao River and Bai River, with five

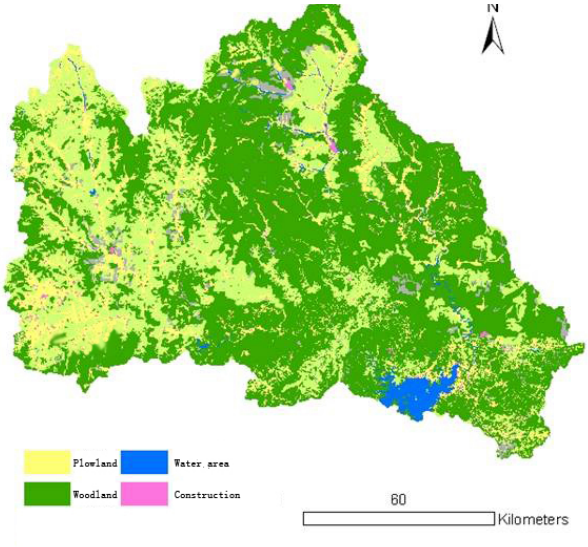



Fig. 2: The spatial distribution of 1995 year land use types in the upper Chaobai River basin.

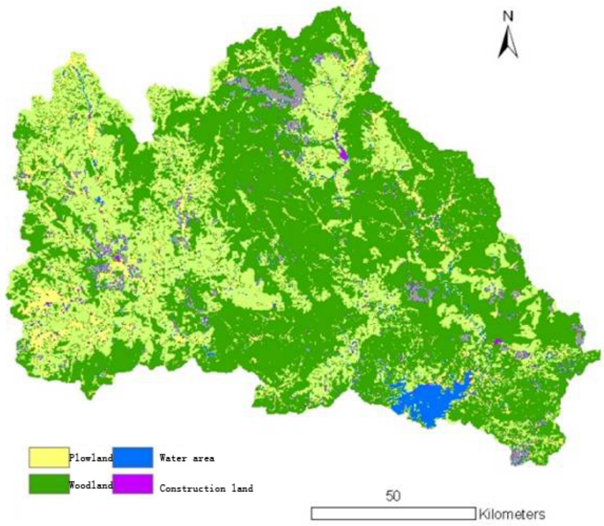



Fig. 4: The spatial distribution of 2015 year land use types in the upper Chaobai River basin.

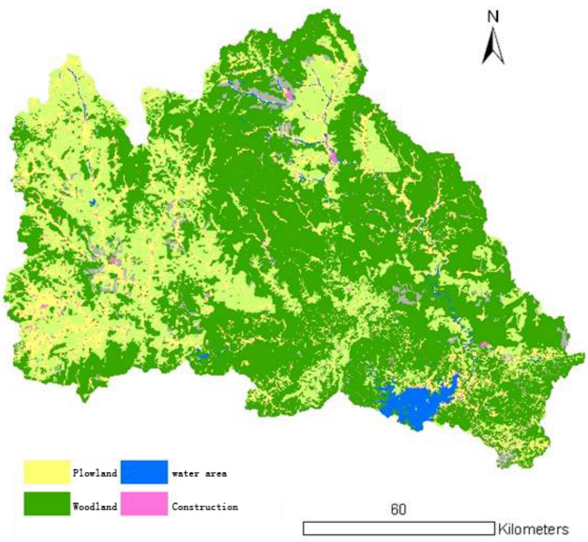



Fig. 3: The spatial distribution of 2005 year land use types in the upper Chaobai River basin.

indicators of water quality and land use as the data source, the correlation between proportion of land-use forms and water quality indicators was analysed (Table 5). As the data of land-use in some area was not normally distributed, Spearman's rank correlation analysis was taken instead. The results showed that forest land and most of the water quality indicators were significantly correlated in the two rivers, while construction land as well as farmland and water quality indicators was not significantly correlated. Overall forest land had a positive effect on water quality while construction land had a negative effect. Besides, the impact of farmland on water quality was complex.

**Redundancy analysis for relationship between water quality parameters and land use:** In order to study water quality parameters influenced by the extent of land use, two sets of variables were raised with five-year average water quality and land use of Chaobai River as a sample (Fig. 3). The redundancy analysis for RDA linear model was advanced through the DCA analysis and gradient calculations of water quality parameters (species data). The results indicated that the eigen values of first two sorting axes were 0.689 and 0.116. The correlation coefficient of first two sorting axes of species and environmental factors were 0.9353 of 0.9592. The model met the significant conditions and the results were satisfactory. As can be seen from RDA sorting maps, total nitrogen, total phosphorus and ammonia nitrogen were positively correlated with the construction land while negatively correlated with forest land and farmland. Permanganate index was positively correlated with construction land and farmland while negatively correlated with forest land. Dissolved oxygen was positively correlated with forest land and farmland while negatively correlated with construction land. Generally, influence of Chao River on water quality parameters was greater than that of Bai Rive. The water quality of Bai River was better. From the time point of view, the water quality of Chaobai River Basin was in decline.

## DISCUSSION

Land use is a comprehensive response of the human activity on space. It affects water quality in two aspects: on the

Table 5: Correlation analysis of land-use composition and water quality in Chaobai River basin.

| Land use forms | Year | Water quality indicators of Chao River | | | | | Water quality indicators of Bai River | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TN | TP | $NH_3$-N | $COD_{Mn}$ | DO | TN | TP | $NH_3$-N | $COD_{Mn}$ | DO |
| Farm land | 1995 | -0.236 | -0.288 | -0.105 | +0.028 | +0.228 | -0.291 | -0.305 | -0.051 | +0.240 | +0.259 |
| | 2000 | -0.175 | -0.225 | -0.002 | +0.087 | +0.159 | -0.291 | -0.185 | -0.005 | +0.270 | +0.159 |
| | 2005 | -0.174 | -0.167 | +0.068 | +0.107 | +0.096 | -0.186 | -0.063 | +0.096 | +0.285 | +0.096 |
| | 2010 | -0.181 | -0.187 | +0.098 | +0.157 | +0.193 | -0.211 | -0.115 | +0.025 | +0.184 | +0.217 |
| | 2015 | -0.185 | -0.205 | +0.055 | +0.128 | +0.208 | -0.193 | -0.187 | +0.008 | +0.125 | +0.115 |
| Forest land | 1995 | -0.316* | -0.216 | -0.404** | -0.301 | +0.061 | -0.211 | -0.199 | -0.396* | -0.320* | +0.025 |
| | 2000 | -0.249 | -0.203 | -0.441** | -0.368* | +0.031 | -0.210 | -0.188 | -0.441** | -0.368* | +0.028 |
| | 2005 | -0.244 | -0.272 | -0.492** | -0.421** | +0.055 | -0.246 | -0.207 | -0.475** | -0.393* | +0.087 |
| | 2010 | -0.284 | -0.222 | -0.421** | -0.475** | +0.096 | -0.261 | -0.191 | -0.490** | -0.360* | +0.113 |
| | 2015 | -0.279 | -0.271 | -0.490** | -0.368* | +0.087 | -0.240 | -0.150 | -0.463** | -0.326* | +0.086 |
| Construction land | 1995 | +0.076 | +0.004 | +0.121 | +0.187 | -0.138 | +0.074 | +0.068 | +0.040 | +0.104 | -0.105 |
| | 2000 | +0.103 | +0.077 | +0.100 | +0.144 | -0.218 | +0.107 | +0.109 | +0.068 | +0.104 | -0.181 |
| | 2005 | +0.091 | +0.161 | +0.122 | +0.255 | -0.340* | +0.116 | +0.163 | +0.132 | +0.203 | -0.294 |
| | 2010 | +0.096 | +0.193 | +0.103 | +0.161 | -0.369* | +0.132 | +0.196 | +0.169 | +0.250 | -0.267 |
| | 2015 | +0.086 | +0.096 | +0.132 | +0.259 | -0.358* | +0.159 | +0.300 | +0.224 | +0.320* | -0.369* |

**indicates significantly related at 0.01 level,* indicates significantly related at 0.05 level

one hand, it affects the volume of nutrient input into water by different human activities and intensity. On the other hand, it changes the roughness of land surface through land thus affects the surface runoff and the process of nutrient entering. Generally in the basin, the greater the proportion of farmland and urban land is, the higher the concentration of nutrients in the river is. And the runoff output load of nutrient in farmland is much higher than that of forest land. In this study, the methods of monitoring and mathematical statistics for water quality and land use were adopted to observe and analyse the regularity between land-use forms and water quality parameters, taking Chaobai River as an example.

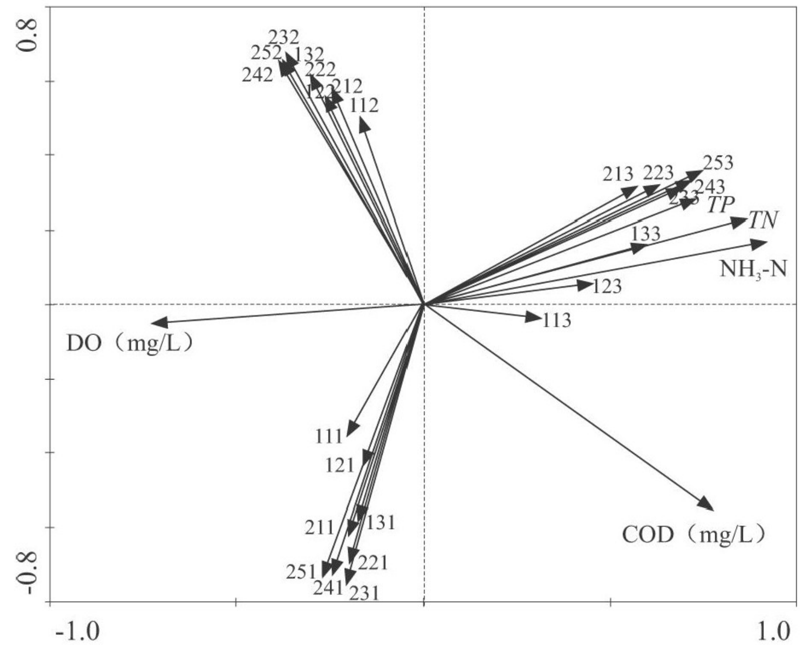
Forest land had significantly positive effect on the water quality. It presented negative correlation with total nitrogen, total phosphorus, ammonia nitrogen, and permanganate index while a positive correlation with dissolved oxygen, indicating that water quality got better with the proportion of forest increasing. Forest land presented a significantly negative correlation with ammonia and permanganate index, indicating that the two pollutants decreased due to forest land. As the forest, understory plants and soil can reduce rainstorm runoff and soil erosion and can adsorb pollutants, which can effectively reduce nutrients input into the river after surface erosion.

The construction land had negative effects on water quality. In the Chaobai River Basin, construction land was negatively correlated with dissolved oxygen while positively correlated with total nitrogen, total phosphorus, ammonia nitrogen and permanganate index, indicating that water quality decreased with the increase of construction land. However, the relevance of construction to water quality parameters was not significant, but was significantly correlated with dissolved oxygen and permanganate index. Construction sites are hosted on high-density population and economic activity and high emission intensity, and impervious construction land is considered to promote the surface runoff, which are likely to increase nutrient concentrations of rivers and reduce water quality.

The impact of farmland on water quality was complex. It was negatively correlated with total nitrogen and total phosphorus while positively correlated with permanganate index and dissolved oxygen. In the1990s it was negatively correlated with ammonia nitrogen while positively correlated after 2000, which was caused by the relation between a large number of farming methods and the use of pesticides and fertilizers after 2000. However, in the basin the correlation was not significant. The farmland can import large quantities of nutrients to the river by fertilization and can absorb and retain pollutants as vegetation or wetland system. Therefore, an total nitrogen and total phosphorus would reduce with the increase of farmland.

## CONCLUSION

Taking Chaobai River Basin as an example in this study, with the methods of water quality monitoring and remote sensing interpretation of land use, the relationship and related factors between land use and water quality were observed and analysed. The results indicated that: forest land had significantly positive effects on water quality. Con-




1**: Bai river basin, 2**: Chao river basin, *1*to*5*: 1995, 2000, 2005, 2010, 2015 year
**10**20**3: farmland, forest land, construction land.
Fig. 5: RDA ordination diagrams of impacts of land-use types on water quality.

struction land had negative effects on water quality. Farmland had complex impacts on water quality. With time going on, point source pollution caused by construction land and non-point source pollution caused by cultivating methods and fertilization increase due to increased human activities. The water quality of Chaobai River Basin from 1995-2015 was decreasing. The results could be used to provide a scientific basis for the land optimization and water pollution control of Chaobai River Basin, as well as guide the policy decision of space development and water environment protection of Chaobai River Basin.

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