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Evolution Characteristics and Driving Forces of Wetland Changes in the Poyang Lake Eco-economic Zone of China

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Abstract: Wetland ecosystem is known as the “kidney” of earth and the “gene pool” of species. It has the functions of regulating climate, flood storage and degradation of pollution. In this paper, based on GIS technology and landscape ecology, wetland changes and its driving forces in the Poyang Lake Eco-economic Zone of China are analyzed. The analysis of landscape pattern demonstrates that there is an increase in the degree of fragmentation of wetlands in the study area. At the same time, the overall aggregation degree of the lake is in the rise. The increased Perimeter-area fractal dimension indicates that the shape of wetland becomes more and more rules. The main driving forces of wetland changes in the Poyang Lake Eco-economic Zone include natural factors and human activities. This study also indicates the main natural factor is the changes of precipitation meanwhile the increase of average temperature. Meanwhile, the rapid population growth, regional economic development and other human activities are also the key driving forces of wetland landscape changes in the Poyang Lake Eco-economic Zone.

Keywords: wetland change; landscape pattern; climate change; ecosystem management; Poyang Lake

1 Introduction

Land use/land cover change (LUCC) in the field of global environmental change research has been gained increasing degree of attention because of its role in the social and ecological environment (Vitousek et al., 1997; Li, 1996). As one of the important land types, wetlands are also increasingly widespread concern by many scholars (Huang et al., 2012; Nagabhatla et al., 2012; Scott et al., 2012). Wetland ecosystem, which is known as the “kidney” of earth and the “gene pool” of species, has become one of the most productive ecosystems on the planet (Whigham, 1999; Cserhalmi et al., 2011). Wetland not only is a valuable natural resource for human survival but also is one of the most important environments (Kingsford, 2011). It not only directly provides the raw material for the production and human life and also some functions of regulating climate, flood storage and control the pollution and degradation of pollution and other environmental function (Traill et al., 2010). The analysis of the driving force of the various wetland changes is one of priorities and focuses of wetlands LUCC research (Akin et al., 2012). The dynamic monitoring and evaluation of wetlands and its driving force have become the hotspot of current wetland changes research (Behera et al., 2012; Jiang et al., 2012; Kayastha et al., 2012; Landmann et al., 2013). At present, a large number of studies show that the driving forces of wetland changes concerned about climate change, vegetation and human disturbance (Guardiola-Albert et al., 2011; Lopez-Merino et al., 2011; Miller et al., 2012; Zhen et al. 2011). Urbanization is an irresistible trend of the development of human society in the 21st century. Most of arable lands have been converted to construction land by urban expansion in China. This made a large number of ecological land including wetlands, which plays a pivotal role in ecological service function, exploited to arable land for meeting the object of arable land protection. The newly formed wetlands in western China were caused primarily by climate warming over that region whereas the newly created artificial wetlands were caused by economic developments (Gong et al., 2010). Therefore, it is meaningful to explore the mechanisms of wetlands evolution.

Poyang Lake Region of China is recognized as one of the fundamental ecological function districts by the World Wide Fund for Nature (WWF). It plays a vital role in the provision of fresh water resources, the maintenance of the regional water balance, the homogenization of the flood, the regulation of regional climate and the conservation of
biological resources (Deng et al., 2011; Yan et al., 2013). In recent years, some activities including reclamation of land from the lake and agricultural development have made wetland of Poyang Lake region change dramatically, which brought increasing obvious ecological problems (Chen et al., 2012; Feng et al., 2012; Shankman and Liang, 2003). In view of the high service value of wetland and the vast eco-environment effect of LUCC, it is necessary to study process and mechanism of wetland in the Poyang Lake Eco-economic Zone (Huang et al., 2012). The Mountain-River-Lake Program (MRL) was implemented since 25 years ago in the Poyang Lake basin, southern China. It consists of series of forest restoration projects that aim to address severe soil and water losses, and improve farmer's livelihoods (Huang et al., 2012). Therefore, the study of changes in wetlands in the Poyang Lake Region of China becomes increasingly urgent. As we all known, the study of wetland landscape pattern can better understand the ecological processes. Exploring the change of natural wetland landscape pattern over time and revealing its driving forces are an urgent need to study the issue for the Poyang Lake (Huang et al., 2012; Yan et al., 2013).

The main purposes of this study are: 1) how to study the characteristics of wetland changes based on the theories and methods of landscape ecology; 2) to explore the evolution pattern of different kinds of wetlands; 3) and to find the driving forces of wetland changes in the Poyang Lake Eco-economic Zone for Sustainable Watershed Management.

2 Materials and Methods

2.1 Study Area

The study area (28°30′N -30°06′N, 114°29′E -117°25′E) is located in Jiangxi Province, a southern region of China, with a surface of approximately 51,200 km² (Figure 1). The area belongs to the subtropical humid climate zone, with an annual average temperature of 16~18 °C and an annual average rainfall of 1,600 mm. Annual average sunshine is about 1,473.3~ 2,077.5 hours. Annual sunshine total radiation is about 97~114.5 Kcal/cm². Soils are predominantly red soil, yellow soil and paddy soil. Poyang Lake is the largest freshwater lake in China and is one of the six wetlands with rich biodiversity in the World. Taking Poyang Lake as the core and relying on the Poyang Lake city circle, the Poyang Lake Eco-economic Region is the significant economic zone for protecting the ecology and developing economics. The study area includes 38 counties and has a population of 20.06 million and GDP of 3,948.17 billion Yuan (RMB) in 2008. One of goals of the study area is to build an international demonstration zone for the harmonious ecological and economic development.

![Figure 1. Location map of Poyang Lake Eco-economic Zone in China](image)
2.2 Data

Land use data of 1990, 2000 and 2005 employed in this study came from the 1:100,000 national land use database of the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC). Wetland types in this study divided into three classes and 11 subclasses (see Table 1). Based on the ArcGIS9.3 software, land use data resampled at the spatial resolution of 100 m × 100 m. Climatic data came from the China Meteorological Data Sharing Service System. Social-economical data at the county level in this study derived from the Jiangxi province statistics yearbook from 1985 to 2006.

Table 1. Wetland classes of the study area.

| Wetland class       | Wetland subclass          |
|---------------------|---------------------------|
| Natural wetland     | Lake                      |
|                     | River                     |
|                     | Lakeshore                 |
|                     | Swamp                     |
| Artificial wetland  | Paddy field               |
|                     | Reservoir and pond        |
| Non-wetland         | Forest                    |
|                     | Grass                     |
|                     | Dry field                 |
|                     | Constructed land          |
|                     | Other non-wetland         |

2.3 Methods

2.3.1 Land dynamic degree

Land dynamic degree is to measure the number of changes in the situation for some time within a certain land use types. The formula is given as:

\[ K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \]  

(1)

Where K is the dynamic degree of a certain land types within the study period; U_a and U_b respectively represent the area of land use types in the beginning and at the end of the study; T is the length of the study period. When T is set for the year, the value of K is the average annual rate of the area change of a certain land type.

2.3.2 Transfer matrix of land use change

On the basis of the transfer matrix of land use types, transition probability matrix of land use types is established to describe the changes in the intensity of land use types. The formula is given as:

\[ D_{ij} = \sum_{ij} \left[ \frac{dS_{i,j}}{S_j} \right] \times 100\% \]  

(2)

Where \( D_{ij} \) is the transition probability of land use type i converted into land use type j in the study period; \( S_i \) is the total area land use type i of the beginning of the study; \( dS_{i,j} \) is the sum of the areas of land use type i converted into the land use type j in the study period; \( n \) is the number of land use types changed in the study area.

2.3.3 Conversion contribution ratios
The transfer matrix method describes the evolution of different land use types. In order to fully reflect the status and role of information of different land types in the land use pattern, the method of conversion contribution ratios of transfer to/from the land use types is conducted in this study. It can comparatively analyze of spatial pattern and quantity characteristics of the transfer-in and transfer-out of the various types of land use. The formula of conversion contribution ratios of transfer-in of land use types is given as:

\[ L_{ji} = \sum_{j=1}^{n} \frac{S_{ji}}{S_i} \]  

Where \( L_{ji} \) means the proportion of the area of other kinds of land use types except \( i \) converted into land use type \( i \) accounting for the total area transferred; \( S_{ji} \) refers to the transfer area of the land use type \( j \) converted to land use type \( i \); \( S_i \) is the total area of land use type transferred; \( n \) is the number of land use types. \( L_{ji} \) can be used to compare the area differences of increment allocated for the various kinds of land in the transfer-in process of land dynamic change.

The formula of conversion contribution ratios of transfer-out of land use types is given as:

\[ L_{0j} = \sum_{j=1}^{n} \frac{S_{ij}}{S_i} \]  

Where \( L_{0j} \) means the proportion of the area of land use type \( i \) converted into other kinds of land use types accounting for the total area transferred; \( S_{ij} \) refers to the transfer area of the land use type \( i \) converted to land use type \( j \); \( S_i \) is the total area of land use type transferred; \( n \) is the number of land use types. \( L_{0j} \) can be used to compare the area differences of decrement allocated for the various kinds of land in the transfer-out process of land dynamic change.

2.3.4 Landscape pattern analysis

Landscape ecology can provide new theories and methods for a comprehensive solution to the resource and environmental problems and to carry out a detailed ecological environment construction. In this study, we selected seven landscape indices to reflect the characteristics of the wetlands changes at landscape and class level.

Number of patches of a particular patch type is a basic measure of the extent of subdivision or fragmentation of the patch type. The formula of Number of Patches (NP) is given as:

\[ NP = n_i \]  

Where \( NP \) represents the Number of Patches; \( n_i \) is the number of patches in the landscape of patch type (class) \( i \).

Patch density has the same basic utility as the number of patches as an index, except that it expresses the number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. The formula of Patch Density (PD) is given as:

\[ PD = \frac{n_i}{A} \]  

Where \( PD \) represents the patch density; \( n_i \) is the number of patches in the landscape of patch type (class) \( i \); \( A \) is the total landscape area.

Largest Patch Index at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a basic measure of dominance. The formula of Largest Patch Index (LPI) is given as:

\[ LPI = \frac{\text{Max}(a_1, \cdots, a_n)}{A} \]  

Where \( LPI \) represents the Largest Patch Index; \( a_i \) is the area of patch (class); \( A \) is the total landscape area.

Perimeter-area fractal dimension is appealing because it reflects shape complexity across a range of spatial scales (patch sizes). A fractal dimension greater than 1 for a 2-dimensional landscape mosaic indicates a departure from a Euclidean geometry (i.e., An increase in patch shape complexity). The formula of Perimeter-area fractal dimension (PAFRAC) is given as:
\[ \ln(P/4) = k \ln(A) + c, PAFRAC = 2k \]  
(8)

Where \( PAFRAC \) represents the Perimeter-area fractal dimension; \( A \) is the area of patch (class); \( P \) is the perimeter of patch (class).

Landscape Division is based on the cumulative patch area distribution and is interpreted as the probability that two randomly chosen pixels in the landscape are not situated in the same patch. The formula of Landscape Division Index is given as:

\[
DIVISION = \left[1 - \sum_{i=1}^{M} \sum_{j=1}^{N} \left( \frac{a_{ij}}{A} \right)^2 \right]
\]
(9)

Where \( DIVISION \) represents the Landscape Division Index \( x \); \( a_{ij} \) is the area of patch (class); \( A \) is the total landscape area.

Shannon's Diversity Index is a popular measure of diversity in community ecology, applied here to landscapes. The formula of Shannon's Diversity Index (SHDI) is given as:

\[
SHDI = -\sum_{i=1}^{m} [P_i \ln(P_i)]
\]
(10)

Where \( SHDI \) represents the Shannon's Diversity Index; \( p_i \) is the proportion of the landscape occupied by patch type (class) \( i \);

Aggregation index is calculated from an adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type appear side-by-side on the map. The formula of Aggregation Index (AI) is given as:

\[
AI = \left[ \frac{g_{ii}}{\max \rightarrow g_{ii}} \right](100)
\]
(11)

Where \( AI \) represents the Aggregation Index; \( g_{ii} \) is the number of like adjacencies (joins) between pixels of patch type (class) \( i \) based on the single-count method.

3 Results and Discussion

3.1 Overall analysis of wetland dynamic changes

The areas and its changes of different kinds of wetland during the period 1990-2005 in the Poyang Lake Eco-economic Zone are listed in the Table 2. From Table 2, we can see that there was an increasing trend of natural wetland and the artificial wetland in the study area showed a decreasing trend from 1990 to 2005. For natural wetland, lake increased from 200, 523 hm\(^2\) in 1990 to 284, 300 hm\(^2\) in 2005, an increase of 41.78%. As can be seen from the Figure 2, there is a rapid growth of the construction land. Figure 2 also shows that the increase in the lake is more obvious from 1990 to 2005 due to the conversion of a large area of the lakeshore.
### Table 2. Wetland change during the period 1990-2005 in the Poyang Lake Eco-economic Zone

| Wetland type          | Area/hm² | 1990 | 2000 | 2005 | Value change /hm² | The Rate of change /% |
|-----------------------|----------|------|------|------|-------------------|-----------------------|
| Natural wetland       |          |      |      |      |                   |                       |
| Lake                  |          |      |      |      |                   |                       |
| River                 |          |      |      |      |                   |                       |
| Lakeshore             |          |      |      |      |                   |                       |
| Swamp                 |          |      |      |      |                   |                       |
| Artificial wetland    |          |      |      |      |                   |                       |
| Paddy field           |          |      |      |      |                   |                       |
| Reservoir and pond    |          |      |      |      |                   |                       |
| Non-wetland           |          |      |      |      |                   |                       |
| Forest                |          |      |      |      |                   |                       |
| Grass                 |          |      |      |      |                   |                       |
| Dry field             |          |      |      |      |                   |                       |
| Constructed land      |          |      |      |      |                   |                       |
| Other non-wetland     |          |      |      |      |                   |                       |

Figure 2. Spatial distribution of wetlands of Poyang Lake Eco-economic Zone in 1990, 2000 and 2005

Figure 3 shows that the dynamic degree of different wetland types during the period 1990-2005 and the period 2000-2005 in the Poyang Lake Eco-economic Zone. As can be seen from the Figure 3, the value of dynamic degree of the lake is largest, 9.22 during the period 2000-2005. The value of dynamic degree of paddy field is smallest, -0.05 during 1990-2005. The value of dynamic degree of most wetland types is negative except lake.
The transfer matrix of different types of wetlands from 1990 to 2005 is listed in the Table 3. Many lakes, rivers, lakeshores, reservoir and ponds transformed into paddy fields, the area respectively 2955hm², 189 hm² and 3072 hm² (see Table 3). This means that many natural wetlands were replaced by the artificial wetlands. As can be seen from the Table 3, 34% of the paddy fields were pushed back the natural wetlands, and 25% of the paddy fields were occupied by the constructed land during the period 1990-2005 in the Poyang Lake Eco-economic Zone. At the same time, there is a greater conversion between the different types of wetlands. The main types mainly transferred to the lakes are the beaches, marshes and rivers.
The conversion contribution ratio of different kinds of wetlands from 1990 to 2005 is listed in the Table 4. Compared with the contribution ratios of other transfer-in landscape components, the contribution ratios of transferring into the lake are the largest, 62.18% during the period 2000-2005 (see Table 4). While the contribution ratio of transfer-in is less than transfer-out during the period 1990-2000, but in general, the contribution ratio of transferring into the lake is greater than transferring out the lake. This is because there are a large number of lakes have been reclaimed into the paddy fields during the period 1990-2000.

| Period      | Conversion type | Lake  | River | Lakeshore | Swamp | Paddy field | Reservoir and pond | Non wetland |
|-------------|-----------------|-------|-------|-----------|-------|-------------|--------------------|-------------|
| 1990-2000   | Transfer-in     | 3.77  | 0.44  | 42.11     | 0.23  | 17.93       | 20.10              | 15.41       |
|             | Transfer-out    | 17.08 | 0.39  | 7.53      | 1.27  | 25.14       | 43.13              | 5.46        |
| 2000-2005   | Transfer-in     | 62.18 | 0.41  | 3.72      | 1.46  | 13.56       | 1.81               | 16.85       |
|             | Transfer-out    | 1.44  | 5.87  | 37.13     | 21.55 | 18.83       | 10.75              | 4.43        |
| 1990-2005   | Transfer-in     | 51.22 | 0.45  | 12.14     | 0.51  | 13.76       | 4.46               | 17.46       |
|             | Transfer-out    | 5.10  | 4.87  | 30.80     | 17.83 | 19.10       | 17.40              | 4.91        |

The concern is that the contribution rate of transferring into or out the landscape components directly or indirectly controlled by the change of the lake in the Poyang Lake Eco-economic Zone. During the period 1990-2000, the conversion contribution ratio of transferring into the lakeshore is the maximum, 42.11% because large areas of ponds and lake converted into lakeshore. During the period 1990-2005, the conversion contribution ratio of transferring into the lake is the maximum, 51.22% due to the large number of the lakeshore and swamp converted into lake. During the period 1990-2000, the conversion contribution ratio of transferring out the paddy field is the maximum, 25.14% due to the large areas of paddy field converted into constructed land. Because of the large areas of lakeshore converted into the lake, the conversion contribution ratio of transferring out the lakeshore is the maximum, 37.13% during the period 2000-2005 and 30.8% during the period 1990-2000. This is mainly because of the increase in rainfall during this period.

3.2 Pattern change of wetland landscape

The change of landscape indices of whole wetland in the Poyang Lake Eco-economic Zone from 1990 to 2005 is listed in Table 5. As can be seen from Table 5, the patch number of wetland landscape increased from 15974 in 1990 to 15988 in 2005, which showed an increasing trend in the Poyang Lake Eco-economic Zone. At the same time, Landscape Division Index (DIVISION) showed a downward trend from 1990 to 2005. It means that the separation degree of wetland increased. According to the changes of Number of Patches (NP) and Landscape Division Index (DIVISION), we can infer that there is an increase in the degree of fragmentation of wetlands in the study area.

| NP  | PD     | LPI    | PAFRAC | DIVISION | SHDI   | AI   |
|-----|--------|--------|--------|----------|--------|------|
| 1990| 15974  | 0.7148 | 9.7702 | 1.5132   | 0.9743 | 1.0361| 82.0775|
| 2000| 16249  | 0.7286 | 9.7818 | 1.5151   | 0.9743 | 1.0361| 81.9827|
| 2005| 15988  | 0.7231 | 9.9693 | 1.5216   | 0.9689 | 0.9942| 82.4600|

Average fractal dimension index means the self-similar degree of the patch, to some extent, and it can reflect the impact degree of human activities on the patch. The Perimeter-area fractal dimension increases from 1.5132 in 1990 to 1.5216 in 2005 (see Table 5). The increase of average fractal dimension means that the shape similarity of wetland landscape patch increases and the shape become more and more rules. This is mainly because of the large number of marsh wetlands reclamation become more regular paddy fields.
From Table 5, we can see that Shannon's Diversity Index (SHDI) decreased from 1.0361 in 1990 to 0.9942 in 2005. Shannon's Diversity Index (SHDI) can reflect the landscape heterogeneity and is extremely sensitive to the non-equilibrium distribution of each patch type in the landscape. It emphasizes the contribution of rare patch types of information. The decrease of Shannon's Diversity Index shows that wetland type in the regional landscape is more monotonous, and the contribution of information of rare patch types reduced.

The result of landscape indices of different kinds of wetlands in 1990 and 2005 is listed in Table 6. In respect of the lake wetland, as can be seen from Table 6, the number patches of the lake are in decline, and the largest patch index shows an upward trend from 1990 to 2005.

Table 6. Landscape indices of different kinds of wetlands in 1990 and 2005

| Type          | Year | NP   | PD    | LPI   | PAFRAC | DIVISION | SHDI  | AI   |
|---------------|------|------|-------|-------|--------|----------|-------|------|
| Lake          | 1990 | 482  | 0.0091| 0.7929| 1.3749 | 98.7594  | 0.9999| 92.7145|
|               | 2005 | 447  | 0.0085| 3.1949| 1.3987 | 99.5089  | 0.9989| 94.6958|
| River         | 1990 | 691  | 0.0131| 0.6528| 1.6611 | 98.7521  | 1.0000| 75.0698|
|               | 2005 | 636  | 0.0121| 0.5283| 1.6534 | 98.5275  | 1.0000| 75.2963|
| Lakeshore     | 1990 | 1292 | 0.0245| 0.2730| 1.4515 | 96.0796  | 1.0000| 83.6639|
|               | 2005 | 1926 | 0.0365| 0.0829| 1.4614 | 92.2784  | 1.0000| 77.2215|
| Swamp         | 1990 | 213  | 0.0040| 0.4486| 1.4568 | 98.5830  | 1.0000| 89.2230|
|               | 2005 | 181  | 0.0034| 0.3696| 1.4296 | 98.4530  | 1.0000| 89.3645|
| Paddy field   | 1990 | 8053 | 0.1526| 4.1375| 1.5515 | 99.4854  | 0.9956| 81.3159|
|               | 2005 | 8178 | 0.1550| 4.1784| 1.5504 | 99.4812  | 0.9957| 81.34  |
| Reservoir and pond | 1990 | 5243 | 0.0994| 0.4455| 1.4297 | 94.7593  | 1.0000| 72.3708|
|               | 2005 | 4620 | 0.0876| 0.4785| 1.4415 | 95.5238  | 1.0000| 71.8425|

The largest patch index (LPI) can reflect the effect degree of the maximum patch on the entire landscape. The increase in the largest patch index of lake indicated that the degree of Poyang Lake landscape controlling the whole wetland showed an enhanced trend. Meanwhile, Aggregation Index (AI) of lake increased from 92.7145 in 1990 to 94.6958 in 2005. It shows that the overall aggregation degree of wetland is in the rise.

As for the swamp wetland, the largest patch index shows a downward trend from 1990 to 2005. Meanwhile, the Perimeter-area fractal dimension decreased from 1.4568 in 1990 to 1.4296 in 2005 (see Table 6). It indicates that the large patch of wetlands is fragmented and becomes increasingly irregular. The increase in the number of patches and reduces patch density of swamp also supports this conclusion.

As for the reservoir and pond, the patch number and largest patch index shows a downward trend from 1990 to 2005. Meanwhile, the Aggregation Index (AI) decreased from 72.37 in 1990 to 71.84 in 2005. The Perimeter-area fractal dimension increased from 1.4297 in 1990 to 1.4415 in 2005 (see Table 6). This means that pond wetland is fragmented and became increasingly regular by the human disturbance.

As can be seen from Table 6, for all wetlands, the patch number and patch density of paddy field is largest. This means that the paddy field is the largest wetland type interfered by human. Aggregation degree of the lake is highest, which means that the connectivity of the lake is the best. Overall, the patch number of artificial wetlands is greater than natural wetlands. Simultaneously, the patch density and separation degree of artificial wetlands is greater than natural wetlands. This is mainly a result of manual interference. Table 6 shows that the connectivity of natural wetlands is higher than artificial wetlands.

3.3 Driving forces of wetland change

The main driving factors of wetland changes in Poyang Lake Eco-economic Zone include natural factors and human activities. Natural factors usually include climate, geology, geomorphology, hydrology, vegetation, soil, and
so on. Human activities are mainly reflected in the demographic, economic, and policy aspects. Natural factors often have a role in the landscape at the larger spatial and temporal scales. In other words, environmental backgrounds control the main changes of wetland. Meanwhile, factors of human activities are the main driving force of the dynamic changes of the wetland at a shorter time scale. Wetland is a special type in the watershed landscape. Water is the fulcrum to maintain its ecological structure and function and spatial characteristics of landscape and is the main carrier of material flow, energy flow and information flow within the wetlands and other land type. Water environment is the motivating factors directly promoting the formation and evolution of wetland.

Atmospheric rainfall becomes main replenishment water for the wetland. How much is precipitation directly impacts on the regional wetland area. Figure 4 shows the change of annual mean precipitation in Poyang Lake Region from 1981 to 2010. According to Table 2, lake decreased from 200,523 hm\(^2\) in 1990 to 194,575 hm\(^2\) in 2000, then increased 284,300 hm\(^2\) in 2005. At the same time, annual precipitation decreased from 1543mm in 1990 to 1455mm in 2000, then 1472mm increased in 2005 (see Figure 4). There is a strong correlation between the average annual rainfall and the area of Poyang Lake. This is mainly because a lot of lakeshore land turned into lakes when annual precipitation is abundant.

\[
y = -3.4825x + 1680.2 \\
R^2 = 0.0073
\]

![Figure 4. Annual mean precipitation of Poyang Lake Region from 1981 to 2010](image)

In addition to the effects of precipitation, temperature changes are also critical factors that affect the wetland landscape changes. Temperature not only affects the vegetation growth status and biomass, but also it affects the process of evaporation, intensity of surface and surface evaporation. Figure 5 shows the change of annual mean temperature in the Poyang Lake Region from 1981 to 2010.
As can be seen from figure 5, in general, the annual average temperature in the Poyang Lake Eco-economic Zone shows a rising trend. From figure 3, we can see that the average annual rainfall of Poyang Lake Ecological Economic Zone shows an overall decreasing trend. Reduced rainfall will reduce the water supply of upstream river runoff on wetlands, reduce soil moisture, exacerbates the drought level, eventually leading to the degradation of the swamp. The rise in temperature will increase the surface evaporation, affecting the wetland area. Meanwhile, some rivers shrinking dry and the many bubble marsh shrink or disappear due to the reduction of water. Therefore, the changes of annual rainfall and temperature become the main driving forces of natural wetlands change.

With the rapid economic development, over-exploitation of wetland resources is the main reason for the loss of a large area of wetlands in the Poyang Lake Eco-economic Zone. This is mainly because the economic development and population growth will inevitably lead to the rapid increase of the construction land and other non-wetlands, which occupied more natural wetlands, especially the beaches.

According to the analysis related statistics, during the period 1990-2005, the non-agricultural population of the Poyang Lake Eco-economic Zone is growing rapidly from 3,591,700 in 1990 to 5,678,500 in 2005, an average annual growth of 139,100. Accordingly, the proportion of the non-agricultural population increased from 21.3% in 1990 to 28.3% in 2005. The proportion of the non-agricultural population growth reflects a trend of urbanization and industrialization. Therefore, industrialization and urbanization are also extremely crucial driving forces of wetland changes in the Poyang Lake Eco-economic Zone. Industrialization and urbanization in the study area has made the land use of non-farm through the population concentration, industry concentration and the geographical spread of occupied land. As the weak link in the land use structure, wetland has become the most obvious type of land use change in the non-agricultural conversion process. In the past 15 years, a large number of ponds and paddy fields occupied for construction land in the study area, which can be seen from Table 3. Therefore, a large number of natural wetlands have gradually reclaimed to the artificial wetlands or artificial landscape in the interference of human activities for economic benefits. It is mainly in the agricultural development activities such as paddy field development and urban construction such as transportation and urban settlements.

Some policies have a profound impact on the wetlands change of Poyang Lake Eco-economic Zone, especially in playing a key role in the process of protecting their reasonable evolution. Since the late 1980s, the study area is in the implementation of the Mountain River Lake Development Program, which is a watershed integrated management
program for the sustainable development of Poyang Lake watershed. The object of the project is to achieve the harmonious development of the economy, society and environment. It has formed a governance guideline "Governing lakes must first regulating the rivers, regulating the rivers must first managing mountains, managing the mountains must reduce poverty ". The implementation of the project has protected the water quality of Poyang Lake and reduced the degradation of wetlands.

Other policies like “cultivated land balance” has negative on the wetland changes of Poyang Lake Eco-economic Zone. In the context of increasing demand for construction land, swamp and pond are facing the threat of agricultural development because of meeting the requirements of “cultivated land balance”. Implementation of forest restoration projects and improve the livelihoods farmers are important measures to protect wetlands in the Poyang Lake Eco-economic Zone. How to use quantified methods, such as correlation analysis, factor analysis, and so on, to explore the driving forces of wetland changes is important for future research.

4 Conclusions

There is an increasing trend of natural wetland and artificial wetland in the study area shows a decreasing trend from 1990 to 2005. The value of dynamic degree of the lake wetland is largest, 9.22 during the period 2000-2005. The main types mainly transferred to the lakes are the beaches, marshes and rivers during the period 1990-2005.

The contribution ratio of transferring into the lake is the largest, 62.18% during the period 2000-2005. Overall, the contribution ratio of transferring into the lake is greater than transferring out the lake from 1990 to 2005. During the period 1990-2005, the conversion contribution ratio of transferring into the lake is the maximum, 51.22% due to the large number of the lake and swamp converted into lake. 25% of the paddy fields were occupied by the constructed land during the period 1990-2005 in the Poyang Lake Eco-economic Zone.

The analysis of landscape pattern indicates that there is an increase in the degree of fragmentation of wetlands in the study area. The Perimeter-area fractal dimension increased from 1.5132 in 1990 to 1.5216 in 2005, which indicates the shape of wetland becomes more and more rules. The Aggregation Index (AI) of lake increases from 92.7145 in 1990 to 94.6958 in 2005, which means that the overall aggregation degree of the lake is in the rise. The aggregation degree of the lake is highest, which means that the connectivity of the lake is the best.

The change of temperature and precipitation of the study area has a significant impact on wetland changes. The rapid population growth, regional economic development and other human activities are also the key driving forces of wetland landscape changes in the Poyang Lake Eco-economic Zone.

The above conclusions in this study provide the basis for the sustainable management and decision-making of the Poyang Lake Watershed.

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References

[1] Akin A, Berberoglu S, Erdogan MA, Donmez C (2012). Modelling land-use change dynamics in a mediterranean coastal wetland using CA-markov chain analysis. Fresenius Environ. Bull. 21: 386-396.
[2] Behera MD, Chitale VS, Shaw A, Roy PS, Murthy MSR (2012). Wetland Monitoring, Serving as an Index of Land Use Change-A Study in Samaspur Wetlands, Uttar Pradesh, India. J. Indian Soc. Remote Sens. 40: 287-297.
[3] Chen P, Chen XL (2012). Spatio-temporal variation of flood vulnerability at the Poyang Lake Ecological Economic Zone, Jiangxi Province, China. Water Sci. Technol. 65: 1332-1340.
[4] Cserhalmi D, Nagy J, Kristof D, Neidert D (2011). Changes in a Wetland Ecosystem: A Vegetation Reconstruction Study Based on Historical Panchromatic Aerial Photographs and Succession Patterns. Folia Geobot. 46: 351-371.
[5] Deng XZ, Zhao YH, Wu F, Lin YZ, Lu Q, Dai J (2011). Analysis of the trade-off between economic growth and the reduction of nitrogen and phosphorus emissions in the Poyang Lake Watershed, China. Ecol. Model. 222: 330-336.
[6] Feng L, Hu CM, Chen XL, Cai XB, Tian LQ, Gan WX (2012). Assessment of inundation changes of Poyang Lake using MODIS observations between 2000 and 2010. Remote Sens. Environ. 121: 80-92.

[7] Gong P, Niu ZG, Cheng X (2010). China’s wetland change (1990–2000) determined by remote sensing. Sci China Earth Sci. 53: 1036–1042.

[8] Guardiola-Albert C, Jackson CR (2011). Potential Impacts of Climate Change on Groundwater Supplies to the Donana Wetland, Spain. Wetlands. 31: 907-920.

[9] Huang LB, Bai JH, Yan DH, Chen B, Xiao R, Gao HF (2012). Changes of wetland landscape patterns in Dadu River catchment from 1985 to 2000, China. Front. Earth Sci. 6: 237-249.

[10] Huang L, Shao QQ, Liu JY (2012). Forest restoration to achieve both ecological and economic progress, Poyang Lake basin, China. Ecol. Eng. 44: 53-60.

[11] Jiang WG, Wang WJ, Chen YH, Liu J, Tang H, Hou P, Yang YP (2012). Quantifying driving forces of urban wetlands change in Beijing City. J. Geogr. Sci. 22: 301-314.

[12] Kayastha N, Thomas V, Galbraith J, Banskota A (2012). Monitoring Wetland Change Using Inter-Annual Landsat Time-Series Data. Wetlands. 32: 1149-1162.

[13] Kingsford RT (2012). Conservation management of rivers and wetlands under climate change - a synthesis. Mar. Freshw. Res. 62: 217-222.

[14] Landmann T, Schramm M, Huettich C, Dech S (2013). MODIS-based change vector analysis for assessing wetland dynamics in Southern Africa. Remote Sens. Lett. 4: 104-113.

[15] Li XB (1996). Core of Global Environmental Change Research: Frontier in Land Use and Coverage Change. Acta Geographica Sinica. 51: 553-558.

[16] Lopez-Merino L, Cortizas AM, Lopez-Saez JA (2011). Human-induced changes on wetlands: a study case from NW Iberia. Quat. Sci. Rev. 30: 2745-2754.

[17] Miller BA, Crumpton WG, van der Valk AG (2012). Wetland hydrologic class change from prior to European settlement to present on the Des Moines Lobe, Iowa. Wetl. Ecol. Manag. 20: 1-8.

[18] Nagabhatla N, Finlayson CM, Sellamuttu SS (2012). Assessment and change analyses (1987-2002) for tropical wetland ecosystem using earth observation and socioeconomic data. Eur. J. Remote Sens. 45: 215-232.

[19] Scott DE, Metts BS (2012). Shifts in an isolated wetland salamander community over 30 yrs: Has climate change altered wetland hydrology? Integr. Comp. Biol. 52: 156-156.

[20] Shankman D, Liang QL (2003). Landscape changes and increasing flood frequency in China's Poyang Lake region. Prof. Geogr. 55: 434-445.

[21] Traill LW, Bradshaw CJA, Delean S, Brook BW (2010). Wetland conservation and sustainable use under global change: a tropical Australian case study using magpie geese. Ecography. 33: 818-825.

[22] Vitousek PM (1997). Human domination of Earth's ecosystems. Sci. 278: 21-21.

[23] Whigham DF (1999). Ecological issues related to wetland preservation, restoration, creation and assessment. Sci. Total Environ. 240: 31-40.

[24] Xie ZL, Liu JY, Ma ZW, Duan XF, Cui YP (2012). The effect of surrounding land use change upon the wetland landscape pattern of natural reserve of Tianjin, China. Int. J. Sustain. Dev. World Ecol. 19:16-24.

[25] Yan D, Schneider UA, Schmid E, Huang HQ, Pan LH, Dilly O (2013). Interactions between land use change, regional development, and climate change in the Poyang Lake district from 1985 to 2035. Agric. Syst. 119: 10-21.

[26] Zhen L, Li F, Huang HQ, Dilly O, Liu JY, Wei YJ, Yang L, Cao XC (2011). Households’ willingness to reduce pollution threats in the Poyang Lake region, southern China. J. Geochem. Explor. 110: 15-22.
鄱阳湖生态经济区湿地景观演变特征及其影响因素分析

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摘要: 湿地被称为地球之“肾”和物种的“基因库”。湿地具有调节气候、调蓄洪水和生物多样性维护等生态功能。本文，基于GIS技术和景观生态学原理，分析了中国鄱阳湖生态经济区湿地的演变特征和驱动力。景观格局分析表明研究区湿地景观平均斑块分维数从1990年的1.5132增加至2005年的1.5216，意味着整个湿地景观变得越来越规则。湖泊湿地的聚集度从1990年的92.7145增加至2005年的94.6958，这表明湖泊湿地的团聚程度在增加。温度和降雨量是导致研究区湿地变化的主要驱动因素。人口的增长、区域经济的发展和人类的开发活动也是导致研究区湿地景观变化的关键因素。

关键词: 湿地变化；景观格局；气候变化；生态系统管理；鄱阳湖
Investigation on cell surface characterization of *Microcystis* spp. in eutrophic freshwater lakes

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Abstract: Cyanobacterial blooms especially toxic *Microcystis* blooms in eutrophic lakes bring a series of public health problems and is hard to control. In this study, the zeta potential and hydrophobicity of *Microcystis* cells in the field during the *Microcystis* blooms periods was investigated. Additionally, the zeta potential of two dominated species of *Microcystis* spp. (*Microcystis aeruginosa* and *Microcystis flos-aquae*) in Lake Taihu and the effect of pH on the zeta potential was studied in the culture experiment. The surface charge of cultured and field *Microcystis* cells was negative, and the zeta potential decreased by increasing pH value which in the range of 3–10, suggesting that the isoelectric point value was less than 3. The growth phase could affect the zeta potential of *Microcystis* cells. The absolute zeta potential value in the stationary phase was higher than that in the exponential phase. There were differences between *Microcystis aeruginosa* and *Microcystis flos-aquae*. The absolute zeta potential value of *Microcystis aeruginosa* was higher than that of *Microcystis flos-aquae*. For hydrophobicity, there were also differences among the colony size of *Microcystis* in the field. The hydrophobicity was higher in the size less than 20 μm, which was beneficial to form large colony to protect them and survive better.

Keywords: *Microcystis*; Zeta potential; Hydrophobicity

1 Introduction

Cyanobacterial blooms especially *Microcystis* blooms are rampant in eutrophicated freshwater lakes, which bring the crisis for the human and ecological health. However, understanding the mechanism of *Microcystis* colonies formation and controlling blooms development still need a lot to explore and research. A lot of studies have showed that predation by zooplankton\(^{1, 2}\), *Microcystin*\(^3\), and nutrients\(^4\) may induce unicellular *Microcystis*
cells to form colony to survive. During the process of form transformation, the surface characterization of cells changed firstly and could give us a direct information. However, the surface characterization of algal cells have received little attention.

As we know, algal cells excret extracellular polymer substances to promote the growth or to protect themselves. These substances contained active functional groups such as hydroxyl, amine, and carboxylic groups, which play a major role in surface binding capacity, biomineralisation, and adhesion\[5, 6\]. The adhesion mechanism was generally dominated by the electrostatic interactions or by the hyrophobicity interactions on the surface, which could be expressed by the zeta potential and the hydrophobicity\[7\]. Hydrophobicity was higher, which was better for the aggregation or the colony formation\[8\]. Additionally, zeta potential was consider to be the useful tool to estimate the efficiency of removal during the water treatment\[9\]. So considering the Microcystis blooms are serious and harmful, understanding the surface characterization of Microcystis cells was essential in explaining the mechanism of colony formation and controlling the blooms. In present study, through combining the field investigation and culture experiment, we investigated the cell surface characterization (zeta potential and hydrophobicity) of Microcystis spp. in eutrophic Lake Taihu.

1 Materials and methods:

2.1 Field samples collection

The field cyanobacteria were collected in eutrophic Taihu lake ecosystem research station (TLLER) in Meiliang Bay during the period from April to October in 2012. During this period, the cyanobacteria samples were collected using plankton net at a fixed site in the station. Then the collected samples were immediately sent to Nanjing Laboratory for the zeta potential measurement. For the hydrophobicity determination, the collected filed cyanobacteria in August were separated into five groups according to the colony sizes, and they are < 20 μm, 20 ~ 100 μm, 100 ~ 200 μm, 200 ~ 400 μm and > 400 μm, respectively. The hydrophobicity of cell surface corresponding to these different sizes were measured.

2.2 Experimental culture

Microcystis spp. including Microcystis aeruginosa (FACHB-1214) and Microcystis flos-aquae (FACHB-1028) in the pure culture were obtained from the institute of hydrobiology, Chinese Academy of Sciences, China. The cells were cultured in BG11 medium, but with 10 times of carbon in BG11, 1/50 times of nitrogen and phosphorus in BG11. Cultures were grown at 25°C, under 39 μmol photons/m²/s irradiance and 12:12 h (light/dark) cycle in the constant temperature incubator. The whole incubation time lasted for 30 days.

2.3 Zeta potential analysis

The charge surface of cells were assessed by a computer with software based on the Helmholtz–Smoluchowski equation\[10\]. The zeta potential was detemined using a JS94G+ microelectrophoresis apparatus made in China\[11\]. Cultured algal suspension was harvested directly in triplicate at low speed centrifugalization and resuspended in 10 ml of 0.1 mol/L NaNO₃. For field algae, disintegration of Microcystis colonies was done by ultrasonic treatment before centrifugalization. The pH of the washed cell suspensions was adjusted from 3 to 10 by HNO₃ or NaOH (0.1 M) addition. The zeta potential was evaluated at room temperature in the electrophoresis cell. For each sample, triplicate cultures were taken for measurement and for each data, approximately, 10 readings were done. The average values were reported in this paper.
2.4 Influence of pretreatment of cells on hydrophobicity

In order to estimate the effect of common pretreatment on hydrophobicity, three ways were included as follows: (1) filtration only; (2) centrifugation only; (3) centrifugation after formalin fixation. Considering the collected field algal colony were floating on the water surface, the low frequency ultrasound was used to make the cells suspend\[12, 13\].

2.5 Hydrophobicity analysis

The hydrophobicity of the cell surface was evaluated by xylene-water two-phase system\[14\]. Field cyanobacterial cells were sonicated firstly and harvested by centrifugation, and then resuspended in 0.2 M sodium hydrogen phosphate buffer (pH=7.0). The concentrations of algal cells counted by Microscope were N₀. A volume of 0.5 mL of xylene was added to 4 mL of cell suspension. The two-phase system was vortexed for 30 s and settled for 15 min. The algal cells in aqueous phase were counted as Nᵯ. The percentage of hydrophobicity (H) was calculated by \( H = \frac{N₀ - Nᵯ}{N₀} \times 100\% \), where N₀ is the cells numbers after settlement and Nᵯ is the cells before settlement.

2.6 Statistical analysis

One-way ANOVA analysis was used between treatment groups, and the difference between them was analyzed by Tukey HSD comparison.

3 Results and discussion:

3.1 Zeta potential

3.1.2 Zeta potential of field cyanobacteria

The zeta potential changes of field cyanobacteria at pH 7.0 at TLLER were shown in Fig. 1. And the values depending on pH value in different seasons were present in Fig. 2.

![Fig. 1 Zeta potential of field Microcystis cells measured in NaNO3 solution at pH 7.0](image-url)
3.1.3 Zeta potential of pure cultured *Microcystis* spp.

The growth curves of *Microcystis aeruginosa* FACHB-1214 and *Microcystis flos-aquae* FACHB-1028 were shown in Fig.3. The exponential phase (0 d-11 d) and stationary phase (15 d-30 d) could be distinguished from this figure. In this paper, day 7 and day 25 were chosen to be typical growth period, which was corresponding to the exponential phase and the stationary phase. The changes of zeta potential of two *Microcystis* species in culture on time and pH values were shown in Fig. 4 and Fig. 5, respectively.
The zeta potential is the potential at the slide surface of a colloid electrical double layer, and it is closely related to the state of charge on the surface of particles. The surface zeta potential of algal cells could affect the physiological status and nutrient absorption. Recently, the cyanobacterial blooms was rampant and serious, the algal zeta potential was also an important affecting factor in engineering treatment\cite{15, 16}. When the surface charge of algal cells was positive, the zeta potential was positive. When the surface charge of algal cells was negative, the zeta potential was negative. The results showed that the zeta potential values on the surface of the cultured and field cyanobacterial cells were both negative, and decreased by increasing pH values. As Fig. 1 and Fig. 4 shown, the zeta potential of field cyanobacteria at pH 7.0 were in the range of $-8.3 \sim -20.9 \text{ mV}$. Among them, the zeta potential of cells in June was similar to the investigated value ($-18 \text{ mV}$) of field cyanobacteria during the blooming period\cite{17}. The zeta potential values of cultured pure *Microcystis* cells at pH 7.0 ranged from $-13.1 \sim -21.0 \text{ mV}$. The values on the cultured cells surface during the exponential phase (Fig. 4 and Fig. 5) were similar to the reported values by Hadjoudja et al\cite{18}. By comparison to the early stage of incubation, the negative charge of cells surface at day 30 was decreased, which meant that the zeta potential was increased. This may be due to the changes of the composition and contents of bound extracellular polymeric substances (bEPS)\cite{19}.
The zeta potentials of algal cells changed by pH values (3 ~ 10) were shown in Fig. 2 and Fig. 5. The results showed that, the zeta potentials of field and cultured *Microcystis* cells were both negative, suggesting that the surface charge of *Microcystis* cells was negative. The zeta potential value at pH 3.0 was still negative, indicating that the isoelectric point was less than 3.0. This result was in agreement with the reported value of *Microcystis* [16-18]. According to the report by Henderson et al [16], the isoelectric point of EPS from *Microcystis aeruginosa* during the exponential phase and stationary phase was about 2. This result showed that the surface characterization of cells could be reflected by the EPS. During the whole culture process, the zeta potential increased by decreasing pH values. When pH value increased from 3 to 5, the zeta potential values decreased rapidly, which may be caused by deprotonation of carboxyl functional groups in the EPS [18, 20].

As shown in Fig. 1, the absolute values of zeta potentials on the filed cyanobacterial cells surface showed a trend of changes from high to low during the seasons from Spring to Autumn. Generally, the absolute values of zeta potential on the cells surface at different pH values in Spring were higher than those in Summer (Fig. 2). The decrease of the absolute zeta potential values means that the reduce of electrostatic repulsive force. When the Van der Wals force was above the repulsive force, the cells in waters were inclined to condense. The cyanobacterial cells in Summer and Autumn were easier to aggregate into colony and then to form blooms. The reduce of the absolute values of zeta potential in Summer, which could help explain that why cyanobacterial colony sizes in Summer and Autumn were larger than those in Spring [21].

As shown in Fig. 5, for both the species of *Microcystis aeruginosa* and *Microcystis flos-aquae*, the absolute zeta potential values of cells surface in the stationary phase were higher than those in the exponential phase, which not only suggested that the growth phase could affect the zeta potential, but also meant that the stability of cells in the exponential phase was worse than that in the stationary phase. So the cells in the exponential phase were easier to form colonies or aggregate with other organic matters. There was still difference of zeta potential between the species. Whatever in the exponential phase or in the stationary phase, the amplitude of variation of zeta potential of *Microcystis aeruginosa* cells was a little larger than that of *Microcystis flos-aquae*. This may be due to the surface variable charge of *Microcystis flos-aquae* cells less than that of *Microcystis aeruginosa* cells. Additionally, we noted that when the pH value was more than 7, the absolute zeta potentials values of *Microcystis flos-aquae* were lower than those of *Microcystis aeruginosa*. However, when the the pH value was less than 7, the absolute zeta potentials values of *Microcystis flos-aquae* were higher than those of *Microcystis aeruginosa* especially during the stationary phase. In natural waters, the pH value was not less than 7 due to the photosynthesis of phytoplankton during the cyanobacterial blooms periods [22]. This suggested that *Microcystis* cells in waters could absorb higher negative charge. Considering *Microcystis aeruginosa* could absorb more negative charge than *Microcystis flos-aquae* during the cyanobacterial blooming periods, the more stability of cells would be for *Microcystis aeruginosa*. In the alkaline aquatic environment, some metals such as manganese ion were relatively insoluble. So the increase of negative charge on the cells surface would be critical for the absorption and settlement [23], which could enhance the capacity of binding cations, and then increase the competition for trace elements such as iron ion. Previous studies have shown that iron limitation was not only important for phytoplankton growth in ocean, but also critical for field cyanobacteria in Lake Taihu, iron supply in Lake Taihu could be beneficial for the growth of *Microcystis aeruginosa* [24]. *Microcystis* cells in natural waters could absorb relatively high negative charge, which absorb more nutrients (such as iron ion) or other cations, and would be beneficial for the *Microcystis* cells to dominate. The results reported by Li et al [25] also showed that the EPS of field *Microcystis* have the strong capacity of binding metals.
3.2 Hydrophobicity

Previous studies have reported that the surface of Microcystis colony was hydrophobic, whereas single cell in culture was hydrophilic\cite{8}. So in this study, the hydrophobicity of single Microcystis cell in culture was so low that it was not detected by xylene-water two-phase system. By comparison of the effect of pretreatment on field algal hydrophobicity, there was little difference between filtration and centrifugation. But the hydrophobicity after formalin fixation was significantly higher than those without fixation ($p < 0.05$), suggesting that formalin fixation changed the characterization of algal surface. In order to avoid formalin to contaminate the samples, choosing filtration or centrifugation for collection would be appropriate.

By determining the hydrophobicity of different colony sizes, there were significant differences among them ($p < 0.05$). The strongest hydrophobicity was seen in the colony size less than 20 $\mu$m, and the weakest one was belonged to the colony size larger than 400 $\mu$m. The hydrophobicity of colony cells with size less than 20 $\mu$m was significantly stronger than that of colony with size between 20 and 100 $\mu$m and size larger than 400 $\mu$m. There were no significant differences between the other sizes. The stronger hydrophobicity suggested that the adhesion capacity of cells surface was stronger, which was more beneficial to the cells aggregate to form colony\cite{8, 26}. As the results shown, the hydrophobicity of colony in small size fraction was stronger than those in large size fraction.
suggesting that a large amount of colony in small size fraction during the early stage of the blooms would be more easier to aggregate to form large colony. According to the result reported by Yang et al[8], the hydrophobicity of *Microcystis* cells was mainly due to the surface polysaccharides. The higher content of monosachrdrides (rhamnose, fucose, and galactose) were in polysaccharides, the stronger hydrophobicity would be[27]. Through the investigation of the compositions of polysaccharides in bEPS of field *Microsystis* colony by Li et al.[25], the ratio of the sum of rhamnose, fucose, and galactose to total polysaccharides was up to 63.3%. So hydrophobicity was the direct good index for the evaluating the cells surface characterization and would be helpful to recoganize the colony formation mechanism.

4 Conclusions:

This paper has presented the surface zeta potential and hydrophobicity of blooming *Microcystis* in the field and in the experimental culture. pH values, growth phase, and the species could affect the surface zeta potential of *Microcystis*. The zeta potential values were negative for cyanobacteria in the filed and in the experiment, and changed by seasons and by culture time. The absolute zeta potential values in Spring were lower than those in Autumn. And the absolute zeta potential values in the stationary phase were higher than those in the exponential phase. Aditonalaly, the zeta potential decreased by increasing pH values (3~10). The hydrophobicity of colony in small size fraction was stronger than that in large size fraction. These informatin would help us to explain the phenomenon of small colony in spring and then form large colony in Summer and Autumn. So this paper has provided a comprehensive knowledge of surface characterization of *Microcystis* for understanding the mechanisms of colony formation during the blooms. Such a recognization will assist in controlling the outbreaks of blooms.

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References:

[1] Burker U, Hyenstrand P, Drakare S, et al. Effects of the mixotrophic flagellate Ochromonas sp. on colony formation in *Microcystis aeruginosa* [J]. Aquatic Ecology, 2001, 35(1): 11-17.
[2] Yang Z, Kong F X. Effects of zooplankton grazing on colony formation in algae: a review. [J]. Acta Ecologica Sinica. 2005, 25(8): 12083-12089.
[3] Gan N, Xiao Y, Zhu L, et al. The role of microcystins in maintaining colonies of bloom ‐ forming *Microcystis* spp [J]. Environmental microbiology, 2012, 14(3): 730-742.
[4] Chen Z, Chen S, Lu G, et al. Phosphorus limitation for the colony formation, growth and photosynthesis of an edible cyanobacterium, *Nostoc sphaeroides* [J]. Biotechnology letters, 2012, 34(1): 137-143.
[5] Pokrovsky O S, Martinez R, GOLUBEV S, et al. Adsorption of metals and protons on *Gloeocapsa* sp. cyanobacteria: A surface speciation approach [J]. Applied Geochemistry, 2008, 23(9): 2574-2588.
[6] Dittrich M, Sibler S. Cell surface groups of two picocyanobacteria strains studied by zeta potential investigations, potentiometric titration, and infrared spectroscopy [J]. Journal of Colloid and Interface Science, 2005, 286(2): 487-495.
[7] Sirmerova M, Prochazkova G, Siristova L, et al. Adhesion of Chlorella vulgaris to solid surfaces, as mediated by physicochemical interactions [J]. Journal of Applied Phycology, 2013, 25(6): 1687-1695.

[8] Yang H, Cai Y, Xia M, et al. Role of Cell Hydrophobicity on Colony Formation in Microcystis (Cyanobacteria) [J]. International Review of Hydrobiology, 2011, 96(2): 141-148.

[9] Riddick T M. Zeta potential: new tool for water treatment [J]. Chem. Eng, 1961, 68(13): 121.

[10] Hong Z, Xiao N Z. Electrokinetic properties of Ferralsols in China in relation to pedogenic development [J]. Geoderma, 1992, 54(1): 173-188.

[11] Hou T, Xu R, Tiwari D, et al. Interaction between electrical double layers of soil colloids and Fe/Al oxides in suspensions [J]. Journal of Colloid and Interface Science, 2007, 310(2): 670-674.

[12] Zhang Y S, Kong F X, Yu Y, et al. The characteristics and buoyancy regulations of cyanobacterial gas vesicles [J]. Acta Ecologica Sinica., 2010(18): 5077-5090.

[13] Zhang Y S, Li H Y, Yu Y, et al. Role of colony intercellular space in the cyanobacteria bloom-forming [J]. Environmental Science., 2011(32): 1602-1607.

[14] Luo Y P, Ma J M, Li Y J, et al. Study on the surface hydrophobicity of Chlorella vulgaris [J]. Chinese Journal Apply Environmental Biology. 1999(5):491-495.

[15] Han M Y, Kim W. A theoretical consideration of algae removal with clays [J]. Microchemical Journal, 2001, 68(2): 157-161.

[16] Henderson R, Passons S, Jefferson B. Successful removal of algae through the control of zeta potential [J]. Separation Science and Technology, 2008, 43(7): 1653-1666.

[17] Sun F, Wu F, Liao H, et al. Biosorption of antimony (V) by freshwater cyanobacteria Microcystis biomass: Chemical modification and biosorption mechanisms [J]. Chemical Engineering Journal, 2011, 171(3): 1082-1090.

[18] Hadjoudja S, Deluchat V, Baudu M. Cell surface characterisation of Microcystis aeruginosa and Chlorella vulgaris [J]. Journal of Colloid and Interface Science, 2010, 342(2): 293-299.

[19] Bernhardt H, Hoyer O, Schell H, et al. Reaction mechanisms involved in the influence of algogenic organic matter on flocculation [J]. Zeitschrift für Wasser-und Abwasser-Forschung, 1985, 18(1): 18-30.

[20] Daughney C J, Tellier X, Chan A, et al. Adsorption and precipitation of iron from seawater on a marine bacteriophage (PWH3A-P1) [J]. Marine chemistry, 2004, 91(1): 101-115.

[21] Cao H, Yang Z. Variation in colony size of Microcystis aeruginosa in a eutrophic lake during recruitment and bloom formation [J]. Journal of Freshwater Ecology, 2010, 25(3): 331-335.

[22] Xu H, Paerl H W, Qin B, et al. Nitrogen and phosphorus inputs control phytoplankton growth in eutrophic Lake Taihu, China [J]. Limnology and Oceanography, 2010, 55(1): 420.

[23] Parker D L, Schram B R, Plude J L, et al. Effect of Metal Cations on the Viscosity of a Pectin-Like Capsular Polysaccharide from the Cyanobacterium Microcystis flos-aquae C3-40 [J]. Applied and environmental microbiology, 1996, 62(4): 1208-1213.

[24] Xu H, Zhu G, Qin B, et al. Growth response of Microcystis spp. to iron enrichment in different regions of Lake Taihu, China [J]. Hydrobiologia, 2013, 700(1): 187-202.

[25] Li P, Cai Y, Shi L, et al. Microbial degradation and preliminary chemical characterization of Microcystis exopolysaccharides from a Cyanobacterial water bloom of Lake Taihu [J]. International Review of Hydrobiology, 2009, 94(6): 645-655.

[26] Fattom A, Shilo M. Hydrophobicity as an adhesion mechanism of benthic cyanobacteria [J]. Applied and environmental microbiology, 1984, 47(1): 135-143.

[27] Vieira A A H, Ortolano P I C, Girolld D, et al. Role of hydrophobic extracellular polysaccharide of Aulacoseira granulata (Bacillariophyceae) on aggregate formation in a turbulent and hypereutrophic reservoir [J]. 2008.
Miniaturized extraction optimized by using response surface methodology, purification and preliminary characterization of naproxen from aqueous and fish samples

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Abstract: Naproxen is a widely used non-steroidal anti-inflammatory drug (NSAID), using for the reduction of pain, fever and inflammation, and thus also released into the aquatic environment, such as lake. Naproxen is chronically toxic to aquatic organisms and bioaccumulates in fish tissue. Here, we propose a new miniaturized naproxen extraction method for aqueous and fish samples by extraction with 1:1 hexane: ethyl acetate and gas chromatography mass spectrometry (GC/MS). Response surface methodology (RSM) was adopted to optimize extraction PH, solvent volume and extraction time. The optimum extraction conditions predicted with the experimental ranges were as follows: pH 2, solvent volume 1.5 mL, and extraction time 5 min. The method was validated using samples fortified with naproxen at levels of 10, 30 and 50 ng/g, the mean recovery exceeds 86%.

Key words: miniaturization, naproxen, response surface modelling, Box-Behnken design

1 Introduction

In recent years, residues of pharmaceuticals have been detected in measurable concentrations in various compartments of the aquatic environment (1, 2). Of all detected pharmaceuticals, the naproxen is consistently detected at higher concentration in the effluents of more WWTPs than other drug (3, 4).

Naproxen [(S)-6-methoxy-α-methyl-2-naphthalene acetic acid] is a widely used non-steroidal
anti-inflammatory drug (NSAID), known for the reduction of pain, fever and inflammation. In the United States, the Food and Drug Administration (FDA) approved its use as an over-the-counter (OTC) drug in 1994. As a consequence of its high amount application, naproxen and its metabolites formed in the human body are excreted unchanged and continuously discharged into municipal wastewaters. In Waste Water Treatment Plants (WWTPs), incomplete elimination of naproxen via biotransformation (5, 6) result in its presence in effluents at concentrations of up to 5.22 µg/L (7) and finally in surface waters at about 0.4 µg/L (8). Therefore, the safety of naproxen has been questioned with regards to environmental and human health. The phototransformation appears to be the main mechanisms of elimination in the environment for naproxen and the photoproducts are more toxic for the aquatic organisms both for acute and chronic values than the parent compound itself (9, 10). This drug is recognized to be highly effective and clinically safe, and the concentration elicit the toxicological effects to fish and other organisms are several magnitudes higher than its found in the environment (11). However, it has been stated that naproxen has some side-effects such as gastrointestinal toxicity, nephrotoxicity, jaundice, hepatotoxicity and induce oxidative stress in the isolated perfused rat liver (12). According to previous report, naproxen and its metabolites have been detected in the bile of rainbow trout (Oncorhynchus mykiss) with bioaccumulation factors of 500 to 2,300 (11).

Zebrafish, a small tropical fish native to the rivers of India and South Asia, is an animal of great scientific interest due to the advantageous features over other vertebrate model systems (13). Low test cost of using adult zebrafish facilitates bioaccumulation kinetics of research, meanwhile zebrafish have over 80% genomic homology to humans, which enables a significant correlation of the data obtained between the two species. In addition, zebrafish is one of the model species recommended by OECD for bioconcentration Test 305, which evaluates the accumulation a dissolved chemical in adult fish by measuring its final concentration in both, the fish and the surrounding media after an equilibration time (14). However, little attention has been devoted to the extraction, purification and characterization in fish sample of naproxen. Herein, we report in detail the optimization of extracting parameters, the purification and the preliminary characterization of naproxen and its metabolites.

The response surface methodology (RSM) has been extensively utilized to optimize culture conditions and medium composition of fermentation process, conditions of enzyme reaction, and processing parameters in the production of food and drug (15). Box-Behnken design (BBD), one of RSM, only have three levels (low, medium and high, coded as -1, 0 and +1), and need fewer experiments. It is more efficient and easier to arrange and interpret experiments in comparison with others (16-18). Therefore, BBD of RSM was used to optimize the extracting parameters of naproxen in the present work. Firstly, single-factor experimental designs (extracting temperature, extracting time, extracting pH, and ratio of extracting solvent to raw material) were carried out before RSM experiments. Secondly, three factors (extracting temperature, extracting time and ratio of water to raw material) were chosen based on single-factor designs for further optimization by employing a three-level, three-variable BBD from RSM. Furthermore, naproxen was purified through liquid-liquid extraction (LLE) and solid-phase extraction (SPE) and the isolated fractions were characterized using GC-MC.
2 Materials and methods

2.1 Reagents and chemicals

Naproxen (purity 98%) and internal standards rac-ibuprofen-d3 (purity 98%) were purchased from Sigma (St. Louis, MO, USA) and J&K Chemical Co., respectively. For the pH-value adjustment, the samples were acidified with 1 N HCl and pH value was measured with the pH meter (Thermo Orion pH meter 520A, Cambridge, UK). Analytical-grade hydrochloric acid (37% Hangzhou, China) used as the reagent, and other solvents used in experiments, including n-hexane, ethyl acetate, acetonitrile, methylene chloride, acetone, methanol) were of HPLC grade and purchased from Tedia Company Inc. (Fairfield, OH, USA). Water was purified in Millipore, Milford, MA, USA). Solid-Phase Extraction (SPE) cartridges (Florisil, 500 mg of absorbent/3 mL of reservoir) were obtained from Anpel Scientific Instrument Co., Ltd (Shanghai, China).

2.2 Reference standard solutions

Standard solution of naproxen was prepared in methanol at the concentration of 1,000 mg/L as stock solution and preserved at 4 °C in the darkness. Working solutions were prepared by a series of 10-fold dilutions of the stock solution and also stored in the dark at 4 °C.

2.3 Sample preparation

Adult zebrafish were blended in a laboratory blender and frozen at -20 °C, before analysis. It showed that no detectable residue of naproxen was contained and it can be used as a negative controls. Screening experiments were carried out on zebrafish spiked with naproxen. The standard naproxen ibuprofen-d3 internal standard solution (100 mg/L in methanol) were spiked into homogenised fish samples and then kept at 4 °C for 24 hours, resulting in a final concentration of 5 μg/g naproxen of sample for use in the evaluation of the subcritical extraction.

The optimisation procedure was applied to the analysis of real samples of adult zebrafish. Adult zebrafish (Danio rerio) obtained from a local commercial fish farm and were acclimated in our laboratory at least for one month before using for experiment. In the experiment, 10 adult zebrafish were randomly distributed in 5L glass tanks containing different concentrations of naproxen (0.1, 1, 10, 100 μg/L) for two months. Three replicates were run for each concentration, and the exposure solutions were renewed completely on a daily basis. During the experiments the water temperature was maintained at 27 ± 1 °C on a light/dark cycle of 12 h: 12 h. The zebrafish were fed twice daily with live brine shrimp. At the end of exposure, zebrafish were taken from the pool, euthanised and stored at -20 °C for later determination.

2.4 Extraction procedure

Fish sample of 200 mg were transferred to 10 mL FEP tube containing 5.0 mL acidified Milli-Q water and 1:1 hexane: ethyl acetate (0.5-1.5 mL) was added followed by vigorous mechanical shaking for 30 sec, ultrasound bath for 5-15 min, and centrifugation at 10000 × g for 2 min, and then the upper organic layer was removed to a clean 5.0 mL glass vial. Lower layer was re-extracted one more time and both organic phases were combined and evaporated to dryness.
using nitrogen gas at 40 °C. Extracts thus obtained were dissolved in 1 mL 7.5:1.5:1 methylene chloride: acetone: methanol.

Extracts were cleaned up by Florisil-SPE column. The cartridges were conditioned with 5 mL methylene chloride and 3 mL 7.5:1.5:1 methylene chloride: acetone: methanol. Above solution was loaded into the cartridge and then 7.5:1.5:1 methylene chloride: acetone: methanol (2 mL) was used to clean the glass vial for three times, in total of 6 mL, followed by loading into the cartridge together and 3 mL n-hexane was used to wash some impurities and fat, followed by air drying the cartridges; naproxen was eluted using 1.5 methanol and then the solvent was evaporated to dryness using nitrogen gas, followed by dissolved in 100 μL 1:1 n-hexane: ethyl acetate. Then, 200 μL of 1N HCl in methanol was added to each sample and heated for 30 min at 80 °C. After the reaction, the solution was extracted two times with 1.0 mL 1:1 n-hexane: ethyl acetate. The organic layer was evaporated to dryness under a stream of nitrogen gas and dissolved in n-hexane (1 mL) and kept until GC/MS analysis. All experiments were carried out in triplicate and the means of results were used for optimisation.

2.5 Optimization of process variables and experimental design

Multiple variables could affect the efficiency of naproxen extraction, the response surface methodology (RSM) is an effective technique for optimising the process (19). Three process variables (sample pH, extraction solvent volume and extraction time) were identified to investigate their influence on the extraction of naproxen form adult zebrafish. In the present work, a three-variable and three-level Box-Behnken design (BBD), a method of response surface methodology (RSM), was applied to optimize the process variables. The coded and uncoded independent variables used in the BBD were listed in Table 1. The levels of the independent parameters were based on preliminary experimental results and research reports (20, 21). The experimental design was based on the Box Behnken design with three central points as shown in Table 2. The experimental data obtained were analyzed by the response surface regression procedure using the following second-order polynomial equation:

\[ Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \]

Where Y is the estimate response (extraction rate%), \( \beta_0 \) is defined as a constant, \( \beta_1, \beta_2 \) and \( \beta_3 \) are the linear coefficients, \( \beta_{11}, \beta_{22} \) and \( \beta_{33} \) are quadratic coefficients, \( \beta_{12}, \beta_{13} \) and \( \beta_{23} \) are interaction coefficients between the three factors. Three-dimensional surface response plots were generated using in fitted model by varying two variables within the experimental range and holding the other constant at the central point. The coefficients of the response surface equation were estimated by using the software of Design Expert 8.0.7.1 (State-Ease, Inc., Minneapolis). The test of statistical significance was based on the total error criteria with a confidence level of 95.0%.

2.6 Chromatographic conditions

An Agilent series gas chromatography mass spectrometry (GC/MS) system was used in this study. The ion source was operated in an electron ionization mode (EI; 70 eV, 230 °C). Select-scan mass spectra (m/z 185) was recorded for analyte identification. The instrument parameters of the GC/MS detector was: splitless mode; t helium gas flow rate, 1.0 mL/min; injector temperature,
310 °C; transfer line temperature, 300 °C; oven temperature, programmed from 140 °C at 12 °C/min to 320 °C (hold for 10 min).

3 Results and discussion

3.1 Experimental design and regression model

The design matrix and the corresponding extraction rates of RSM experiments to determine the effects of the three independent variables including pH (X₁), extraction solvent volume (X₂) and extraction time (X₃) were presented in Table 2. According to these experimental results, the model for the predicted response Y could be expressed by the following empirical second-order polynomial equation (in the form of coded values):

\[
Y = 36.49 - 23.68X_1 + 14.69X_2 - 1.74X_3 + 14.40X_1^2 - 0.55X_2^2 - 1.10X_3^2 + 1.56X_1X_2 + 1.90X_1X_3 - 1.09X_2X_3
\]

The analysis of variance (ANOVA) is shown in Table 3. The significance of the model was determined using F-test. The value of the coefficient of determination (R²) and adjusted coefficient of determination were 0.9739 and 0.9268, respectively, indicating that a high degree of correlation between the observed and predicted values. For any of the terms in the model, a large F-values and a small P-value would be more significant (22). The F-value of 20.71 and p<0.05 implied this model was significant. Conversely, the F-value and P-value of the lack of fit were 9.53 and 0.0964, respectively, which implied that it was not significant (p>0.05). The significance of each coefficient was determined using F-value and P-value. The results were given in Table 3. It could be seen that the linear parameters (X₁, X₂) and one quadratic terms (X₁²) were significant (p<0.05). Results also showed that the independent variable X₁ was the most significant factor on the extraction rate of naproxen.

3.2 Three dimensional (3D) response surface

It has been reported that 3D response surface plots was a function of two factors, maintaining all other factors at fixed levels helpful in understanding both the main and their interaction effects of these two factors (23). Thus, in order to gain a better understanding of the effect of independent variables on a dependent variable, 3D response surface plots were shown in Fig. 1(A)-(C).

Fig. 1(A) illustrates the effect of extraction pH and solvent volume on the extraction rate. When extraction time was fixed at 0 level, the extraction rate increased with increasing extraction solvent volume (X₂) and declined with the pH (X₁). Extraction rate increased sharply when the pH decreased from 4 to 2, indicating that the high recovery for extraction of naproxen was at lower pH value. As shown in Fig. 1(B), when extraction solvent volume was fixed at 0 level, the extraction rate was increased with decreases in pH. However, the influence of the extraction time on the extraction rate is negligible. The results of Fig. 1(C) showed that when pH was fixed at 0 level, the extraction rate was increased with increase in extraction solvent volume and extraction time displayed negligible effect on the extraction rate.

3.3 Optimization of extraction condition
The naproxen extraction conditions would be considered optimum if the extraction rate reached maximum value. From the solutions predicted by the model, the experimental conditions set at the pH of 2, extraction solvent volume 1.5 mL and extraction time 5 min, could give an extraction rate of 90.78%. Under the optimum conditions, the experimental extraction rate was 89.7% (N=3), which was close to the predicted value.

3.4 Results of method validation

Under the optimum conditions described, the calibration curves were linear ($R^2=0.9923$) over the range of 25-500 ng/ml. The accuracy and precision of the method were determined using fish samples fortified with naproxen at levels 10, 30 and 50 ng/g. All experiments were repeated four times. The mean recovery of naproxen was above 86%.

| Experiment no. | X_1 | X_2 | X_3 | Extraction rate(%) |
|----------------|-----|-----|-----|-------------------|
| 1              | -1  | -1  | 0   | 66.19             |
| 2              | -1  | 0   | -1  | 77.69             |
| 3              | -1  | 0   | 1   | 64.88             |
| 4              | -1  | 1   | 0   | 86.23             |
| 5              | 0   | -1  | -1  | 14.91             |
| 6              | 0   | -1  | 1   | 19.16             |
| 7              | 0   | 1   | -1  | 52.70             |
| 8              | 0   | 1   | 1   | 52.58             |
| 9              | 1   | -1  | 0   | 11.32             |
| 10             | 1   | 0   | -1  | 30.90             |

### Table 1 Uncoded and coded independent variables used in Box Benken Design

| Symbols | Independent variable | Coded levels |
|---------|----------------------|--------------|
| X_1     | pH                   | 2 3 4        |
| X_2     | Extraction solvent volume(ml) | 0.5 1 1.5 |
| X_3     | Extraction time (min) | 5 10 15     |

### Table 2 Experimental points of the Box-Benken design and the experimental data

| Experiment no. | X_1 | X_2 | X_3 | Extraction rate(%) |
|----------------|-----|-----|-----|-------------------|
|                |     |     |     | Experimental       | Predicted       |
| 1              | -1  | -1  | 0   | 66.19             | 60.89           |
| 2              | -1  | 0   | -1  | 77.69             | 77.11           |
| 3              | -1  | 0   | 1   | 64.88             | 69.84           |
| 4              | -1  | 1   | 0   | 86.23             | 87.15           |
| 5              | 0   | -1  | -1  | 14.91             | 20.79           |
| 6              | 0   | -1  | 1   | 19.16             | 19.5            |
| 7              | 0   | 1   | -1  | 52.70             | 53.36           |
| 8              | 0   | 1   | 1   | 52.58             | 46.7            |
| 9              | 1   | -1  | 0   | 11.32             | 10.4            |
| 10             | 1   | 0   | -1  | 30.90             | 25.94           |
Table 3 Analysis of variance for the response surface quadratic model

| Source    | Sum of squares | DF | Mean square | F-value | P-value |
|-----------|----------------|----|-------------|---------|---------|
| Model     | 7060.06        | 9  | 784.45      | 20.71   | 0.0019  |
| $X_1$     | 4487.83        | 1  | 4487.83     | 118.46  | 0.0001  |
| $X_2$     | 1726.96        | 1  | 1726.96     | 45.58   | 0.001   |
| $X_3$     | 24.15          | 1  | 24.15       | 0.64    | 0.4608  |
| $X_1X_2$  | 9.77           | 1  | 9.77        | 0.26    | 0.6333  |
| $X_1X_3$  | 14.4           | 1  | 14.4        | 0.38    | 0.5645  |
| $X_2X_3$  | 4.77           | 1  | 4.77        | 0.13    | 0.7371  |
| $X_1^2$   | 765.68         | 1  | 765.68      | 20.21   | 0.0064  |
| $X_2^2$   | 1.12           | 1  | 1.12        | 0.029   | 0.8705  |
| $X_3^2$   | 4.46           | 1  | 4.46        | 0.12    | 0.7454  |
| Residual  | 189.42         | 5  | 37.88       |         |         |
| Lack of fit | 177.04     | 3  | 59.01       | 9.53    | 0.0964  |
| Pure error | 12.38         | 2  | 6.19        |         |         |

DF, degree of freedom
Fig. 1 Surface plot of the naproxen extraction rate from adult zebrafish
References

[1] Zuccato E, Castiglioni S, Fanelli R, et al. Pharmaceuticals in the environment in Italy: Causes, occurrence, effects and control. Environmental Science and Pollution Research, 2006, 13: 15-21.

[2] Nikolaou A, Meric S, Fatta D. Occurrence patterns of pharmaceuticals in water and wastewater environments. Analytical and Bioanalytical Chemistry, 2007, 387: 1225-1234.

[3] Metcalfe C D, Koenig, B. G., Bennie, D. T., Servos, M., Ternes, T. A. & Hirsch, R. . Occurrence of neutral and acidic drugs in the effluents of Canadian sewage treatment plants. Environmental Toxicology and Chemistry, 2003, 22: 2972-2880.

[4] Lishman L, Smyth S A, Sarafin K, et al. Occurrence and reductions of pharmaceuticals and personal care products and estrogens by municipal wastewater treatment plants in Ontario, Canada. Science of the Total Environment, 2006, 367: 544-558.

[5] Ternes T A. Occurrence of drugs in German sewage treatment plants and rivers. Water Research, 1998, 32: 3245-3260.

[6] Quintana JB W S, Reemtsma T. Pathways and metabolites of microbial degradation of selected acidic pharmaceutical and their occurrence in municipal wastewater treated by a membrane bioreactor. Water Res, 2005, 39: 2654-2664.

[7] Andreozzi R, Marotta R, Paxeus N. Pharmaceuticals in STP effluents and their solar photodegradation in aquatic environment. Chemosphere, 2003, 50: 1319-1330.

[8] Ollers S, Singer H P, Fassler P, Muller S R. Simultaneous quantification of neutral and acidic pharmaceuticals and pesticides at the low-ng/l level in surface and waste water. Journal of Chromatography A, 2001, 911: 225-234.

[9] Tixier C, Singer H P, Oellers S, Muller S R. Occurrence and fate of carbamazepine, clofibric acid, diclofenac, ibuprofen, ketoprofen, and naproxen in surface waters. Environmental Science & Technology, 2003, 37: 1061-1068.

[10] Isidori M, Lavorgna M, Nardelli A, et al. Ecotoxicity of naproxen and its phototransformation products. Science of the Total Environment, 2005, 348: 93-101.

[11] Brozinski J M, Lahti M, Oikari A, Kronberg L. Detection of naproxen and its metabolites in fish bile following intraperitoneal and aqueous exposure. Environmental Science and Pollution Research, 2011, 18: 811-818.

[12] Yokoyama H, Horie T, Awaaz S. Naproxen-induced oxidative stress in the isolated perfused rat liver. Chemico-Biological Interactions, 2006, 160: 150-158.

[13] Teraoka H, Dong, W., Hiraga, T., . Zebrafish as a novel experimental model for developmental toxicology. Congenit. Anom 2003, 43: 123-132.

[14] OECD. Test no. 305. Bioconcentration: flow-through fish test. In: OECD Series on Testing and Assessment. Organisation for Economic Co-operation and Development (OECD). http://www.oecdilibrary.org/oecd/content/book/9789264070462-en., 1996.
[15] Qiao D L, Hu B, Gan D, et al. Extraction optimized by using response surface methodology, purification and preliminary characterization of polysaccharides from Hyriopsis cumingii. Carbohydrate Polymers, 2009, 76: 422-429.

[16] Box G E P, & Behnken, D. W. Some new three level designs for the study of quantitative variables. Technometrics, 1960, 2: 455-475.

[17] Wang Y X, Lu Z X. Optimization of processing parameters for the mycelial growth and extracellular polysaccharide production by Boletus spp. ACCC 50328. Process Biochemistry, 2005, 40: 1043-1051.

[18] Ferreira S L C, Bruns R E, Ferreira H S, et al. Box-Behnken design: An alternative for the optimization of analytical methods. Analytica Chimica Acta, 2007, 597: 179-186.

[19] Bas D, Boyaci I H. Modeling and optimization I: Usability of response surface methodology. Journal of Food Engineering, 2007, 78: 836-845.

[20] Togola A, Budzinski H. Analytical development for analysis of pharmaceuticals in water samples by SPE and GC-MS. Analytical and Bioanalytical Chemistry, 2007, 388: 627-635.

[21] Shin H S, Oh J A. Simultaneous determination of non-steroidal anti-inflammatory drugs in river water by gas chromatography-mass spectrometry. Journal of Separation Science, 2012, 35: 541-547.

[22] Chen W, Wang W P, Zhang H S, Huang Q. Optimization of ultrasonic-assisted extraction of water-soluble polysaccharides from Boletus edulis mycelia using response surface methodology. Carbohydrate Polymers, 2012, 87: 614-619.

[23] Yetilmeszoy K, Demirel S, Vanderbei R J. Response surface modeling of Pb(II) removal from aqueous solution by Pistacia vera L.: Box-Behnken experimental design. Journal of Hazardous materials, 2009, 171: 551-562.
Short-term TN and TP prediction by back propagation artificial network based on genetic algorithm in Poyang Lake Basin, China

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Abstract: For the traditional BP algorithm (BP ANN), there exist some shortcomings, such as converging too slowly and being easily trapped into a local optimum. In this study, a hybrid prediction method (the hybrid GA-BP ANN) was proposed, which integrated the BP’s capability of nonlinear and GA’s global search ability. Moreover, the hybrid GA-BP ANN has been employed to predict the short-term Total Nitrogen (TN) and Total Phosphorus (TP) in Poyang Lake Basin and been evaluated its performances. Compared against the traditional BP ANN, the proposed method shows a better performance for the short-term TN and TP prediction, with lower average relative deviation (ARD) ranging from 1.11 to 3.65, and higher coefficient of determination ($R^2$; 0.95—0.98) and Nash-Sutcliffe coefficient of efficiency (NSE; 0.93—0.98) during the training and test stages. Overall, the hybrid GA-BP ANN method is an effective method and can be an alternative model for the prediction.

Key words: artificial neural network; hybrid GA-BP ANN; Genetic Algorithm; Poyang Lake Basin; water quality prediction.

1 Introduction

Nitrogen and phosphorus are the most important biogenic elements of the primary productivity and the food chain of water body, and are also the key limiting factors of water eutrophication (Lapointe and Herren, 2013), which can produce algal toxins, and then directly threaten the health of the water body and public safety (Codd, 2000; Anderson et al., 2002; Lapointe and Herren, 2013). Therefore, to develop a technology of the short-term nitrogen and phosphorus prediction becomes especially necessary. Some traditional prediction methods, such as experience model and deterministic model (e.g., QUAL (Steve Chapra et al., 2008), MIKE (Paliwal and Patra, 2011) and SWAT (Neitsch S.L. et al., 2005)), can simulate nitrogen and phosphorus concentration of water body. However, it is very expensive and time-consuming to obtain huge amounts of data (e.g., long term of daily rainfall, runoff, sediment and water quality data) for modeling. Moreover, high requirements of the model users make these models difficult or unavailable to be widely applied in solving practical problems (Suen and Eheart, 2003;
Concentration of nitrogen and phosphorus in water body can be affected by many factors (e.g., temperature, pH and dissolved oxygen) (Mcqueen and Lean, 1987). Because of the complex and nonlinear relationship among these factors, there are high uncertainties in the traditional methods for the short-term nitrogen and phosphorus prediction (Omer Faruk, 2010). Thus, a new effective and accurate method for predicting the short-term nitrogen and phosphorus in water body is in great need to be developed. In the last two decades, with the leapfrog development of computer hardware and software, high speed computing performance of computer provides a solid platform for the developments of artificial intelligence technology. Methods involving artificial neural network (ANN) is believed to be an effective tool for dealing with non-linear problems, and have been gradually applied in various water resources problems, such as hydrological processes (Akinc and Akkoyunlu, 2012; Senkal et al., 2012; Ramana et al., 2013; He et al., 2014), soil erosion (Ulke et al., 2009; Olawoyin et al., 2013), water resources management (Maier, H. R. and Dandy, 2000; Maier, Holger R. et al., 2010; Orzepowski et al., 2014), groundwater problems (Sahoo, G.B. et al., 2005; Nolan et al., 2012; Kilicaslan et al., 2014), and water quality prediction (Chen, D.J. et al., 2010; Kim et al., 2012; Karakaya et al., 2013). Therefore, the ANN method can also be considered as an alternative for the short-term nitrogen and phosphorus prediction in water body.

For the ANN method, the back propagation (BP) algorithm has been applied widely. However, the ANN trained by BP algorithm (BP ANN) often suffers from converging too slowly and being easily trapped into a local optimum (Bakhkhahi, 2012; Li et al., 2013). In recent, some scholars stated that the training process of ANN can be considered as a classical optimization problem (Alexandridis et al., 2014), and the determination of ANN structure, parameters (e.g., weights, threshold and bias) play a crucial role in training accuracy and generalization ability for ANN (Heuwelmans et al., 2006). With the development of new swarm intelligence algorithms, such as Particle Swarm Optimization (PSO) algorithm (Afshar and Kazemi, 2012; Liu, S.Y. et al., 2013b), Ant Colony Optimization (ACO) algorithm (Hou et al., 2014), and Genetic Algorithm (GA) (Liu, X.D. et al., 2014), more and more swarm intelligence algorithms have been applied in optimizing the parameters of ANNs based on the global search ability (Zhu et al., 2009; Zhang, B. et al., 2012). For instance, Zhang et al. (Zhang, B. et al., 2012) introduced PSO algorithm into optimizing the parameters of RBF ANN, and used the PSO-RBF model to assess underground water assessment. The evaluation results show that the PSO-RBF simulated grades are in accord with those obtained by other evaluation methods. Hou et al. (Hou et al., 2014) proposed improved Pareto ACO algorithm (PACA) for optimal spatial allocation of water resources, results of the improved PAMA are superior to those of other intelligent optimization algorithms including ACO, multi-objective GA and BP ANN. Compared with the traditional ANNs, these hybrid algorithms not only accelerate the convergence rate, but also are easier to obtain the global optimal solution.

Compared to PSO and ACO, GA has a relative mature convergence analysis method with estimable convergence rate, and has the ability to deal with discrete problems (Assareh et al., 2010; Khansary and Sani, 2014). As a global and advanced algorithm with a strong ability to search global optimum, an increasing number of ANN models coupled with GA have been proposed (El-Enam and Al-Rabeh, 2011; Opher and Ostfeld, 2011; Liu, S.Y. et al., 2013a; Liu, X.D. et al., 2014). For example, Toro et al. (Toro et al., 2013) compared a hybrid system (CBR) trained by GA against other well-known artificial intelligence techniques and several statistical tools, the results demonstrate the superiority of the proposed hybrid system for accurate river flow forecasts. Liu et al. (Liu, S.Y. et al., 2013a) proposed a hybrid approach of support vector regression (SVR) with real-value GA optimization (RGA-SVR) for aquaculture water quality prediction, the experimental results demonstrate that RGA-SVR outperforms the traditional SVR and BP ANN.

In addition, GA has also been used to train deterministic models. Sahoo (Sahoo, D. et al., 2010) used GA for optimizing model parameters for the Hydrologic Simulation Program-Fortran (HSPF), and the loosely coupled GA-HSPF model shows a more objective and less time-consuming ability than traditional ones. Similarly, GA can be also adopted for SWAT model parameter optimization (Zhang, X.S. et al., 2009; Zhang, X.S. et al., 2010). Thus, these studies have revealed that GA is a powerful, potential approach to train ANNs and other models.

Despite a high level of water quality prediction accuracy in some researches, improving the performance of the prediction model is still the first-line goal of this present study, which focuses on developing an effective and accurate hybrid model for the short-term nitrogen and phosphorus prediction. Combining with a variety of known understandings, including field monitoring, laboratory analysis and artificial intelligence modeling, we proposed a BP ANN coupled with GA (the hybrid GA-BP ANN) for the short-term nitrogen and phosphorus prediction in Poyang Lake Basin. For this model, the genetic algorithm is introduced to adjust and optimize the connection
weights of BP ANN, to overcome its premature convergence problem and to accelerate the convergence speed, and finally to achieve the global optimum. To evaluate the performance of this proposed model, a comparison between Total Nitrogen (TN) and Total Phosphorus (TP) predictions from the hybrid GA-BP ANN and the traditional BP ANN was carried out.

2 Materials and Methods

2.1 Study area description

Poyang Lake Basin is the largest freshwater lake in China, located in the southern bank of the Yangtze River, north of Jiangxi province. The water surface area of the lake changes greatly with seasons, reaching its maximum of more than 4125 km² in high water level (20m) and minimum of less than 500 km² in low water level (12m). This lake is primarily fed by five big rivers including Gan River, Rao River, Xin River, Fu River and Xiu River. Moreover, it belongs to subtropics moist monsoon climatic region, with moderate climate, adequate lighting, and abundant rainfall (annual average precipitation is 1636 mm).

Four typical sampling sites including Kangshan (S1), Lianhu (S2), Duchang (S3) and Hamashi (S4; Fig.1) within the Poyang Lake were employed to investigate the short-term TN and TP predictions based on the locations of the sites, which are almost in a line from south to north in Poyang Lake.

![Fig.1 Study area and monitoring stations in Poyang Lake Basin, China](image)

2.2 Hybrid GA-BP ANN

GA is one of the evolutionary algorithms, a stochastic search technique with large and complicated search spaces (Liu, S.Y. et al., 2013a) based on ideas from natural genetics and evolutionary principle (Goldberg and Holland, 1988; L.Davis, 1991). In 1975, the idea of this method, which was inspired by the theory of natural evolution, was firstly proposed by Professor John Holland from Michigan University. Compared with traditional optimization algorithms, the superiority of the GA are, firstly, it hardly fall into local optima in the search process, even if the definition of the fitness function is not continuous, irregular or noise, it can also find the global optimal solution with great probability (Song, 2013). Secondly, due to the inherent parallelism, GA is very suitable for large-scale parallel computer (Bahlous et al., 2013; Song, 2013).

To solve optimization problems, GA works with a population of individual strings (chromosomes), each representing a possible solution (Goldberg and Holland, 1988). Abiding by the law of “survival of the fittest”, each chromosome is assigned a fitness value according to the result of the fitness function. Highly fit chromosomes are given more opportunities to reproduce, named reproduction; and then the chromosomes are produced by two genetic operations: crossover and mutation. From generation to generation, the offspring sharing features taken from their parents finally converge to the best chromosome at the end of the evolution. Therefore,
GA can be summarized as two operation processes: genetic operators (including crossover and mutation) and evolutionary operators (selection).

In this present study, a hybrid GA-BP ANN is proposed based on GA’s global search ability and BP’s nonlinear capability. Thus, the hybrid GA-BP ANN can not only overcome the blindness of optimizing process, but also avoid the occurrence of local convergence (Koehler, 1997). The structure and the algorithm process of the hybrid GA-BP model are detailed in Fig. 2.

![Fig. 2 The BP ANN process optimized by Genetic Algorithm](image)

2.3 Evaluation criteria

In this study, the predictability of the proposed models can be evaluated by average relative deviation (ARD), coefficient of determination ($R^2$) and the Nash-Sutcliffe coefficient of efficiency (NSE) (Nash and Sutcliffe, 1970). The ARD, $R^2$ and NSE are expressed by the following equations, respectively:

$$\text{ARD} = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{Q_p - Q_o}{Q_o} \right| \times 100\%$$  \hspace{1cm} (1)

$$R^2 = \left( \frac{\sum_{i=1}^{N} (Q_o - \bar{Q}_o)(Q_p - \bar{Q}_p)}{\left( \sum_{i=1}^{N} (Q_o - \bar{Q}_o)^2 \right)^{0.5} \left( \sum_{i=1}^{N} (Q_p - \bar{Q}_p)^2 \right)^{0.5}} \right)^2$$ \hspace{1cm} (2)

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\[ NSE = 1 - \frac{\sum_{i=1}^{N} (Q_o - Q_p)^2}{\sum_{i=1}^{N} (Q_o - \bar{Q}_o)^2} \]  

Where \( N \) is the number of sample data. \( Q_p \) and \( Q_o \) is the simulated and the observed data, separately. \( \bar{Q}_p \) is the average of the simulated, while \( \bar{Q}_o \) is the average of the observed.

3 Dataset preprocessing

(1) Determination and selection of water quality indices

In the present study, the dataset from S1, S2, S3 and S4 were monitored with equal time intervals in rainy, average flow and dry seasons during 2009 to 2010. Combining with field monitoring and laboratory analyses, eight water quality indices (Table 1) including water Temperature (\( T, \degree C \)), pH, Dissolved Oxygen (DO, milligrams per liter), Ammonia Nitrogen (\( NH_4^+ - N \), milligrams per liter), Permanganate Index (CODmn, milligrams per liter), Five days’ Biochemical Oxygen Demand (BOD5, milligrams per liter), Total Nitrogen (TN, milligrams per liter) and Total Phosphorus (TP, milligrams per liter), were measured by the national standard methods.

| Indices   | Unit          | S1          | S2          | S3          | S4          | CV (%) | Cor.(TN) | Cor.(TP) |
|-----------|---------------|-------------|-------------|-------------|-------------|--------|----------|----------|
|           | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    | Av | Ra    |
| T         | °C  |       | 19. | 9.0~28.1 | 19. | 9.0~28.0 | 17. | 12.0~24. | 17. | 12.7~24. | 29.7 | 2 |
| pH        | —   |       | 7.2 | 6.76~7.5 | 7.1 | 6.73~7.4 | 7.6 | 7.32~7.8 | 7.5 | 7.24~7.7 | 3.92 | 0.14 | 0.25 |
| DO        | mg/L |       | 8.6 | 7.43~9.9 | 8.4 | 7.58~9.5 | 8.3 | 7.88~8.7 | 8.2 | 7.90~8.6 | 10.0 | 0.37 | 0.33 |
| NH4+-N    | mg/L |       | 0.3 | 0.18~0.5 | 0.8 | 0.11~1.9 | 0.3 | 0.13~0.3 | 0.2 | 0.09~0.4 | 6.24 | 0.47 | 0.26 |
| CODmn     | mg/L |       | 2.8 | 2.63~2.9 | 2.7 | 2.38~3.1 | 2.9 | 2.50~3.3 | 3.1 | 2.63~3.5 | 23.0 | -0.1 | -0.0 |
| BOD5      | mg/L |       | 1.5 | 1.38~1.9 | 1.9 | 1.63~3.0 | 1.4 | 1.00~2.1 | 1.5 | 1.00~1.9 | 50.8 | 0.23 | 0.08 |
| TN        | mg/L |       | 1.0 | 0.86~1.3 | 1.7 | 0.82~3.4 | 0.8 | 0.77~0.9 | 0.8 | 0.76~0.9 | 14.3 | 8 | 1.00 |
| TP        | mg/L |       | 0.1 | 0.10~0.2 | 0.2 | 0.12~0.2 | 0.1 | 0.24~0.2 | 0.1 | 0.08~0.2 | 67.4 | 0.59 | 1.00 |

Av, annual average; Ra, Range; CV, coefficient of variation, %; Cor.(TN), correlation coefficient between TN and the other indices; Cor.(TP), correlation coefficient between TP and the other indices.
Table 1 shows that the annual average of NH$_4^+$-N, BOD$_5$, TN and TP at S2 are significantly higher than the others, probably because of the extrinsic factors, such as anthropogenic sources (S2 located below the Lianhu Bridge). Consequently, the dataset from S1, S3, and S4 are selected for the present work.

(2) Interpolation

Given the dataset collected in this work, to carry out monthly short-term TN and TP prediction, three values should be interpolated between each two adjacent time points so that the frequency of the dataset was improved to per month.

The interpolation method was realized by interpolation function programming based on Matlab R2012b platform. Through comprehensively comparing of four kinds of interpolation function [i.e., Linear (linear interpolation), Nearest (near point interpolation), Cubic (cubic polynomial interpolation) and Spline (cubic spline interpolation)], the Spline function was finally adopted in this study. The time range was defined as $t (t = 1.00, 1.25... 6.00)$, where the integers represented the real monitoring time and the decimals represented the interpolation time from 2009 to 2010. Thus, each sampling site was interpolated to 21 samples. Fig.3 shows the observed and the interpolated series, and the interpolation function curves in S1 site.

![Fig.3 The fluctuations of each water quality index based on the Spline function in S1 site](image)

(3) Normalization

As a data-driven ANN model, data preprocess can significantly influence the model performance. For equally being treated for all the variables in training and test stages, the input and output variables have been normalized.
to range from 0.1 to 0.9, which is preferable when a logistic activation function whose outputs are between 0-1 was used in the network (Nash and Sutcliffe, 1970), the normalization equation is given as:

$$x_i = 0.1 + 0.8 \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

(4)

Where $x_{\max}$ and $x_{\min}$ are the maximum and minimum of the input and output data, respectively.

4 Architecture

In this present study, two water quality indices, (t+1)-month concentration of Total Nitrogen and Total Phosphorus, hereafter denoted by TN$_{t+1}$ and TP$_{t+1}$, respectively, were determined as the output variables of the hybrid GA-BP ANN. Moreover, eight water quality indices (Table 1) can be chosen as the network input variables. However, some studies have shown that increased input variables may increase the complexity of the neural network, resulting in low efficiency of the algorithm and poor prediction effect (Jeong et al., 2006). By analyzing the correlation of the eight water quality indices (Table 1), CODmn has poor correlation with both TN and TP (-0.23 and -0.17, respectively), consequently, seven variables of t-moth (i.e., T$_t$, pH$_t$, DO$_t$, NH$_4^+$-N$_t$, BOD$_5_t$, TN$_t$, TP$_t$) were finally chosen as the input variables (Fig.4).

Fig.4 Input and output variables of the hybrid GA-BP model for short-term TN and TP prediction

After dataset preprocessing, the available dataset were generally divided into training and test subsets for developing the hybrid GA-BP model. The training set was used to estimate the unknown parameters (e.g., weights, threshold and bias), and the test set was used to assess the generalization ability of the trained model (Wen et al., 2013). In this study, 42 samples of data from S1 and S3 were selected as training set and the other 21 samples of data from S4 were selected as test set, respectively. The main parameters of the hybrid GA-BP model are listed in Table 2, and the other parameters are set as default values. Note that traditional BP model uses the same parameters as the hybrid GA-BP model except for population size and the maximum generation.

| Parameter           | Description            | Value  |
|---------------------|------------------------|--------|
| net.trainParam.show | Learning rate          | 0.1    |
| net.trainParam.goal | Expected error         | 0.001  |
| net.trainParam.epochs | The maximum iterating epoch | 1000  |
| num                 | Population size        | 40     |
| gen                 | The maximum generation | 100    |

The optimum number of the hidden-layer neurons was determined by the minimum ARD value of TN and TP prediction based on the trail and error procedure. An experiment was performed with a variation of 3-11 neurons. To avoid contingency, each architecture configuration was implemented for 50 runs with different initializations. And then, the average value of ARD was calculated to evaluate the performance of the hybrid GA-BP model with different neurons (Table 3).

Table 3 Performance statistics of the hybrid GA-BP model with different neurons
Table 3 shows that when the number of hidden-layer neurons is less than 8, the performance (ARD) for TN and TP prediction gradually decreases for both training and test. Nevertheless, when the neurons is more than 8, the ARD for TN and TP prediction changes very slightly for training set. Meanwhile, the ARD presents a more or less rising trend for test set, revealing that excessive number of hidden-layer neurons may result in “overfitting” for training, and reduce the generalization ability of the network (Tetko et al., 1995). Hence, the number of the hidden-layer neurons is finally determined to 8, and the hybrid GA-BP ANN architecture is 7—8—2.

5 Results and discussion

Using the proposed hybrid GA-BP ANN model with architecture of 7—8—2 and the traditional BP ANN, we predicted the short-term TN and TP in Poyang Lake Basin (Fig.5 and 6). It is important to note that, the traditional BP ANN was trained under the same condition (i.e. input and output variables, the number of hidden-layer neurons) as the hybrid GA-BP’s for comparison, other scenarios were not considered, as only in this way can the improvement brought by GA be contrastively analyzed.

As depicted in Fig.5 and 6, both the simulated TN and TP from the different models generally fluctuate around the observed. Related to the traditional BP ANN, the simulated TN and TP from GA-BP ANN model are much closer to the observations, basically indicating this proposed model can capture the characteristics of the TN and TP fluctuations better during both the training and test stages.
Fig. 5 Observed and predicted TN and TP during training stage.

BP ANN:
ARD=9.63, NSE=0.81
GA-BP ANN:
ARD=3.65, NSE=0.98

BP ANN:
ARD=4.54, NSE=0.78
GA-BP ANN:
ARD=1.11, NSE=0.93

BP ANN:
ARD=6.03, NSE=0.79
GA-BP ANN:
ARD=2.42, NSE=0.94
Moreover, Figs. 7-10 show the scatter plots of the predicted TN and TP from these two models against the observed data. For the traditional BP ANN (see Figures 7 and 9), the points which are related to TN and TP concentration are situated at a distance below the 1:1 line for both training set and test set, suggesting the simulated TN and TP are lower than the observed value. Meanwhile, a worse performance was obtained for test stage than training stage of the model. Whereas for the hybrid GA-BP ANN (see Figures 8 and 10), the points are situated at a very close distance to the 1:1 line, and the performances are almost the same for both training and test stages.

This phenomenon in the application of ANNs has been reported in the works of Chen et al. (Chen, L. et al., 2012) and Zhang et al. (Zhang, J.R. et al., 2007), and the reason for this shortcoming is the premature convergence problem of the BP ANN, in other words, the BP ANN is easily trapped into a local optimum with bad generalization ability, resulting in lower accuracy of test set than that of training set.
Fig. 9 Scatter plots of the traditional BP ANN simulated and observed TN and TP for test set

Fig. 10 Scatter plots of the hybrid GA-BP ANN simulated and observed TN and TP for test set

Graph showing the comparison of MSE between BP ANN and the hybrid GA-BP ANN.
Further more, the values of $R^2$ shown in Fig.7-10, when combined with ARD and NSE aforementioned in Fig.5 and 6 show that, for short-term TN prediction, the hybrid GA-BP ANN presents a better performance with ARD of 1.53 and 1.11, $R^2$ of 0.95 and 0.98, and NSE of 0.98 and 0.93 for training set and test set, respectively, than the traditional BP ANN. Similarly, for short-term TP prediction, the model performance is superior for the hybrid GA-BP ANN, as indicated by lower ARD (3.65 and 2.42) and higher $R^2$ (0.95 and 0.97) and NSE (0.98 and 0.94) compared with the traditional BP ANN for both training set and test set, respectively. Meanwhile, according to the curves of Mean Square Error (MSE) versus epoch of the traditional BP ANN and the hybrid GA-BP ANN, which is shown in Fig.11, the hybrid GA-BP ANN is superior in terms of convergence rate and accuracy, as indicated by fewer iterations and lower MSE, revealing that the hybrid GA-BP ANN has been overcome the premature convergence problem of BP ANN by optimizing the connection weights of BP ANN, and finally achieve the global optimum.

It should be noted that, as new exploration, the application of the hybrid GA-BP ANN for short-term TN and TP prediction is still at the primary stage. In the present study, there are still some uncertain aspects including the number of the training and test subsets, the influence of the interpolation method and the optimization of the network structure, which need to be further explored. Nevertheless, it can be concluded that the hybrid GA-BP ANN proposed outperforms the traditional BP ANN, and can be an alternative model for short-term TN and TP prediction in Poyang Lake Basin.

6 Conclusion

In this study, a new hybrid GA-BP ANN model is developed and is applied to predict the short-term TN and TP in Poyang Lake Basin. Comparing the performance of the hybrid GA-BP ANN against the traditional BP ANN, the evaluation results are very encouraging even with a relatively small number of dataset employed for training and test. Therefore, conclusion can be drawn as, for short-term TN and TP prediction, the hybrid GA-BP ANN performed better than the traditional BP ANN, with a lower ARD, and higher $R^2$ and NSE during both the training and test stages. In addition, the simulated TN and TP of the proposed model fluctuates better around the observed than the traditional BP ANN, revealing that the proposed model has efficiently overcome the shortage premature convergence of the traditional BP ANN, and can be considered as an alternative model in predicting the short-term TN and TP in Poyang Lake. Moreover, new hybrid ANNs based on the other swarm intelligence algorithms (i.e., PSO and ACO) will be a focus. In the future, we will follow up on this subject and focus on developing new hybrid models to solve more realistic problems.

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References

Afshar, A., and Kazemi, H. 2012. Multi objective calibration of large scaled water quality model using a hybrid particle swarm optimization and neural network algorithm, *KSCE Journal of Civil Engineering*, 16(6), 913-918.

Akiner, M. E., and Akkoyunlu, A. 2012. Modeling and forecasting river flow rate from the Melen Watershed, Turkey, *Journal of Hydrology*, 456, 121-129.

Alexandridis, A., Chondrodima, E., Efthimiou, E., Papadakis, G., Vallianatos, F., and Triantis, D. 2014. Large Earthquake Occurrence Estimation Based on Radial Basis Function Neural Networks, *IEEE Transactions on Geoscience and Remote Sensing*, 52(9), 5443-5453.

Anderson, D. M., Gibert, P. M., and Burkholder, J. M. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences, *Estuaries*, 25(4B), 704-726.

Assareh, E., Behrang, M. A., Assari, M. R., and Ghanbarzadeh, A. 2010. Application of PSO (particle swarm optimization) and GA (genetic algorithm) techniques on demand estimation of oil in Iran, *Energy*, 35(12), 5223-5229.

Bahlous, S. E. O., Neifar, M., El-Borgi, S., and Smaoui, H. 2013. Ambient vibration based damage diagnosis using statistical modal...
fitting and genetic algorithm: A bridge case study, Shock and Vibration, 20(1), 181-188.

Bakhbakh, Y. 2012. Neural network modeling of ternary solubilities of 2-naphthol in supercritical : A comparative study, Mathematical and Computer Modelling, 53(7-8), 1932-1941.

Chen, D. J., Lu, J., and Shen, Y. N. 2010. Artificial neural network modelling of concentrations of nitrogen, phosphorus and dissolved oxygen in a non-point source polluted river in Zhejiang Province, southeast China, Hydrological Processes, 24(3), 290-299.

Chen, L., Kao, S. J., and Traore, S. 2012. Predicting and managing reservoir total phosphorus by using modified grammatical evolution coupled with a macro-genetic algorithm, Environmental Modelling & Software, 38, 89-100.

Codd, G. A. 2000. Cyanobacterial toxins, the perception of water quality, and the prioritisation of eutrophication control, Ecological Engineering, 16(1), 51-60.

El-Emam, N. N., and Al-Rabeh, R. H. 2011. An intelligent computing technique for fluid flow problems using hybrid adaptive neural network and genetic algorithm, Applied Soft Computing, 11(4), 3283-3296.

Goldberg, D., and Holland, J. 1988. Genetic Algorithms and Machine Learning, Machine Learning, 3(2-3), 95-99.

He, Z. B., Wen, X. H., Liu, H., and Du, J. 2014. A comparative study of artificial neural network, adaptive neuro fuzzy inference system and support vector machine for forecasting river flow in the semiari mountain region, Journal of Hydrology, 509, 379-386.

Heuvelmans, G., Muys, B., and Feyen, J. 2006. Regionalisation of the parameters of a hydrological model: Comparison of linear regression models with artificial neural nets, Journal of Hydrology, 319(1-4), 245-265.

Hou, J. W., Mi, W. B., and Sun, J. L. 2014. Optimal spatial allocation of water resources based on Pareto ant colony algorithm, International Journal of Geographical Information Science, 28(2), 213-233.

Jeong, K. S., Kim, D. K., and Joo, G. J. 2006. River phytoplankton prediction model by Artificial Neural Network: Model performance and selection of input variables to predict time-series phytoplankton proliferations in a regulated river system, Ecological Informatics, 1(3), 235-245.

Karakaaya, N., Evrendilek, F., Gungor, K., and Onal, D. 2013. Predicting Diel, Diurnal and Nocturnal Dynamics of Dissolved Oxygen and Chlorophyll-a Using Regression Models and Neural Networks, Clean-Soil Air Water, 41(9), 872-877.

Khansary, M. A., and Sani, A. H. 2014. Using genetic algorithm (GA) and particle swarm optimization (PSO) methods for determination of interaction parameters in forecasting multicomponent systems of liquid-liquid equilibria, Fluid Phase Equilibria, 365, 141-145.

Kilicaslan, Y., Tuna, G., Gezer, G., Gulez, K., Arkoc, O., and Potirakis, S. M. 2014. ANN-Based Estimation of Groundwater Quality Using a Wireless Water Quality Network, Int J Distrib Sens N.

Kim, R. J., Loucks, D. P., and Stedinger, J. R. 2012. Artificial Neural Network Models of Watershed Nutrient Loading, Water Resources Management, 26(10), 2781-2797.

Koehler, G. J. 1997. New directions in genetic algorithm theory, Ann Oper Res, 75, 49-68.

L.Davis.1991. Handbook of Genetic Algorithms, Van Nostrand Reinhold, New York.

Lapointe, B. E., and Herren, L. W. 2013. Eutrophication and Macroalgal Blooms in Coastal Waters of South Florida: Taxonomic Composition and N: P Ratios, Phycologia, 52(4), 58-59.

Li, M., Huang, X., Liu, H., Liu, B., Wu, Y., Xiong, A., and Dong, T. 2013. Prediction of gas solubility in polymers by back propagation artificial neural network based on self-adaptive particle swarm optimization algorithm and chaos theory, Fluid Phase Equilibria, 356, 11-17.

Liu, S. Y., Tai, H. J., Ding, Q. S., Li, D. L., Xu, L. Q., and Wei, Y. G. 2013a. A hybrid approach of support vector regression with genetic algorithm optimization for aquaculture water quality prediction, Mathematical and Computer Modelling, 58(3-4), 458-465.

Liu, S. Y., Xu, L. Q., Li, D. L., Li, Q. C., Jiang, Y., Tai, H. J., and Zeng, L. H. 2013b. Prediction of dissolved oxygen content in river crab culture based on least squares support vector regression optimized by improved particle swarm optimization, Computers and Electronics in Agriculture, 95, 82-91.

Liu, X. D., Zhou, Y. Y., Hua, Z. L., Chu, K. J., Wang, P., Gu, L., and Chen, L. Q. 2014. Parameter identification of river water quality models using a genetic algorithm, Water Sci Technol, 69(4), 687-693.

Maier, H. R., and Dandy, G. C. 2000. Neural networks for the prediction and forecasting of water resources variables: a review of modelling issues and applications, Environmental Modelling & Software, 15(1), 101-124.

Maier, H. R., Jain, A., Dandy, G. C., and Sudheer, K. P. 2010. Methods used for the development of neural networks for the prediction of water resource variables in river systems: Current status and future directions, Environmental Modelling and Software, 25(8), 891-909.

Mcqueen, D. J., and Lean, D. R. S. 1987. Influence of Water Temperature and Nitrogen to Phosphorus Ratios on the Dominance of Blue-Green-Algae in Lake St-George, Ontario, Can. J. Fish. Aquat. Sci., 44(3), 598-604.

Nash, J. E., and Sutcliffe, J. V. 1970. River flow forecasting through conceptual models part I — A discussion of principles, Journal of Hydrology, 10(3), 282-290.

Neitsch S.L., Arnold J.G., Kiniry J.R., and Williams J.R. 2005. Soil and water assessment tool's theoretical documentation, version 2005Rep., Texas Water Resources Institute, College Station, Texas.

Nolan, B. T., Malone, R. W., Gronberg, J. A., Thorp, K. R., and Ma, L. 2012. Verifiable metamodels for nitrate losses to drains and groundwater in the Corn Belt, USA, Environmental Science and Technology, 46(2), 901-908.
Olawoyin, R., Nieto, A., Grayson, R. L., Hardisty, F., and Oyewole, S. 2013. Application of artificial neural network (ANN)-self-organizing map (SOM) for the categorization of water, soil and sediment quality in petrochemical regions, Expert Systems with Applications, 40(9), 3634-3648.

Omer Faruk, D. 2010. A hybrid neural network and ARIMA model for water quality time series prediction, Engineering Applications of Artificial Intelligence, 23(4), 586-594.

Ophe, T., and Ostfeld, A. 2011. A coupled model tree (MT) genetic algorithm (GA) scheme for biofouling assessment in pipelines, Water Research, 45(18), 6277-6288.

Orzepowski, W., Paruch, A. M., Pulikowski, K., Kowalczyk, T., and Pokladek, R. 2014. Quantitative and qualitative assessment of agricultural water resources under variable climatic conditions of Silesian Lowlands (Southwest Poland), Agricultural Water Management, 138, 45-54.

Paliwal, R., and Patra, R. R. 2011. Applicability of MIKE 21 to assess temporal and spatial variation in water quality of an estuary under the impact of effluent from an industrial estate, Water Sci Technol, 63(9), 1932-1943.

Ramana, R. V., Krishna, B., Kumar, S. R., and Pandey, N. G. 2013. Monthly Rainfall Prediction Using Wavelet Neural Network Analysis, Water Resources Management, 27(10), 3697-3711.

Sahoo, D., Smith, P. K., and Ines, A. V. M. 2010. Autocalibration of HSPF for simulation of streamflow using a genetic algorithm, Transactions of the Asabe, 53(1), 75-86.

Sahoo, G. B., Ray, C., and Wade, H. F. 2005. Pesticide prediction in ground water in North Carolina domestic wells using artificial neural networks, Ecological Modelling, 183(1), 29-46.

Senkal, O., Yildiz, B. Y., Sahin, M., and Pestemalci, V. 2012. Precipitable water modelling using artificial neural network in Çukurova region, Environmental Monitoring and Assessment, 184(1), 141-147.

Song, B. 2013. Feasibility of Quantum Genetic Algorithm in Optimizing Construction Scheduling, Delft University of Technology.

Steve Chapra, Greg Pelletier, and Tao, H. 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11: Documentation and Users Manual, Civil and Environmental Engineering Dept., Tufts University, Medford, MA., Steven.

Suen, J. P., and Eheart, J. W. 2003. Evaluation of neural networks for modeling nitrate concentrations in rivers, Journal of Water Resources Planning and Management-Asce, 129(6), 505-510.

Tetko, I. V., Livingstone, D. J., and Luik, A. I. 1995. Neural-Network Studies .1. Comparison of Overfitting and Overtraining, Journal of Chemical Information and Computer Sciences, 35(5), 826-833.

Toro, C. H. F., Meire, S. G., Galvez, J. F., and Fdez-Riverola, F. 2013. A hybrid artificial intelligence model for river flow forecasting, Applied Soft Computing, 13(8), 3449-3458.

Ulke, A., Tayfur, G., and Ozkul, S. 2009. Predicting Suspended Sediment Loads and Missing Data for Gediz River, Turkey, Journal of Hydrologic Engineering, 14(9), 954-965.

Wen, X. H., Fang, J., Diao, M. N., and Zhang, C. Q. 2013. Artificial neural network modeling of dissolved oxygen in the Heihe River, Northwestern China, Environmental Monitoring and Assessment, 185(5), 4361-4371.

Zhang, B., Wang, J. Y., and Zhang, S. L. 2012. A New PSO-RBF Model for Groundwater Quality Assessment, Advanced Materials Research II, Pts 1 and 2,463-464, 922-925.

Zhang, J. R., Zhang, J., Lok, T. M., and Lyu, M. R. 2007. A hybrid particle swarm optimization-back-propagation algorithm for feedforward neural network training, Applied Mathematics and Computation, 185(2), 1026-1037.

Zhang, X. S., Srinivasan, R., and Bosch, D. 2009. Calibration and uncertainty analysis of the SWAT model using Genetic Algorithms and Bayesian Model Averaging, Journal of Hydrology, 374(3-4), 307-317.

Zhang, X. S., Srinivasan, R., and Van Liew, M. 2010. On the use of multi-algorithm, genetically adaptive multi-objective method for multi-site calibration of the SWAT model, Hydrological Processes, 24(8), 955-969.

Zhu, C. J., Zhao, X. J., and Zhou, J. H. 2009. ANN based on PSO for Surface Water Quality Evaluation Model and Its Application, Ccde 2009: 21st Chinese Control and Decision Conference, Vols 1-6, Proceedings, 3264-3268.
Simulation investigation of relationship between water level and surface area of Poyang Lake in typical hydrologic years

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Abstract: Poyang Lake is the biggest fresh water lake in China, where water level and surface area are crucial parameters to the lake ecosystem. With the purpose of exploring the relation between water level and surface area, EFDC hydrodynamic model was used to simulate surface area of Poyang Lake base on the watershed borderline data, geomorphology data of lakebed and water level data of five upper course streams and seven stream outlet in typical years. A statistical model relationship was developed between simulated surface and actual water level data which were collected from four stations including Kangshan, Tangyin, Duchang and Xingzi. Furthermore, the statistical relationship was tested and verified by using remote sensing data of typical years. The result indicated that relation between water level and surface area of Poyang Lake is high dynamic during typical years and the statistical model has a good reliability as the errors between outputs and the actual surface areas are small.

Keywords: Poyang Lake; EFDC; water level; surface area; numerical simulation

1 Introduction

Poyang Lake is a river-connecting lake, located in the south of the middle and lower reaches of The Yangtze river, and its latitude is between 28°24'N and 29°46'N, longitude 115°49'E and 116°46'E. The topography of the lake region is like a “Bowel”, the slope of lake basin is from southeast to northwest). Due to the double impacts of five rivers flows (Ganjiang river, Fuhe river, Xinjiang river, Raohe river, Xiushui river) importing into the lake and...
the withstanding of water level in the Yangtze River. The annual and interannual variabilities of the water level are large. The annual maximum amplitude is 9.59m to 15.36m, interannual maximum variability is 16.69m\(^3\).[5]

Generally, water level get start to grow up to the flood period owing to an increasing amount of rainfall since late March, it reach the peak from June to August and it does not decrease until October, the following year in March is the dry season, the water level dropped, bottomland bare. In the area, the highest water level is 22.59m (Hukou station, July 31, 1998), the corresponding water surface area is about 4, 070 km\(^2\), the lowest water level 5.9m, (Hukou station, February 6, 1963), and river-connecting lake area is less than 200 km\(^2\)[1,4], the area change significantly.

Lake area is an important ecological variable and it can be extracted by remote sensing information and actual measurement or calculated by the statistical relationship between the water level and area. Such as Ding (2010) measured the area curve of reservoir water level by combined with DEM and remote sensing[2]. Zhang (2012) etc. used the remote sensing data to estimate relationship between the level and the area of Poyang Lake[11]. Liu (2011) etc. studied the relationship model of water area of Poyang and water level of Hukou[6].

Due to the complex terrain of Poyang Lake, the traditional assessment methods are not only time-consuming, but also difficult and costly. The method of remote sensing exist the shortcomings of timeliness and low temporal resolution. Therefore, how to calculate the surface area of Poyang effectively and quickly is a problem that deserves to be discussed.

In this paper, in order to build the statistical relationship of Lake area and water level for deducing the surface areas by actual water levels, four sites in different parts of upstream and downstream in Poyang Lake were selected, daily surface area data of high temporal resolution were simulated on the basis of numerical simulation of hydrodynamic model, statistical model of that was built up by correlation analysis of actual water level and lake area in four sites. Finally, the statistical model was verified by surface area data using remote sensing methods.

2 Methodology and Data Sources

2.1 Hydrodynamic model and main control equation

In this paper, the lake area data were gotten by the hydrodynamic model, and used to build the statistic model of water level and lake area. The basic hydrodynamic model is EFDC (Environmental Fluid Dynamics Code) model, which is developed by the Virginia Institute of Marine and funded by the United States Environmental Protection Administration. It combined with hydrodynamic, sediment, contaminants transport and water quality etc.. The EFDC model can be used to simulate the 1-dimensional, 2-dimensional, 3-dimensional numerical variables on different temporal and spatial scales (such as Lake, reservoir, estuarine, bay and wetland etc.)[9,10].

EFDC model adopts orthogonal curvilinear coordinate in the horizontal direction but sigma coordinate in the vertical direction. The momentum equation is:

\[
\begin{align*}
\partial_t \left( m, m, Hu \right) + \partial_x \left( m, Hau \right) + \partial_y \left( m, m, wu \right) - \left( mf + v \partial_x m, -u \partial_y m \right) H = \nabla \left( m, \frac{A}{H} \right) + Q, \\
\partial_t \left( m, H \right) + \partial_x \left( H, h - \partial_x H \right) \partial_x p \partial_y \left( m, \frac{A}{H} \right) + Q,
\end{align*}
\]

(1)

\[
\begin{align*}
\partial_t \left( m, m, Huv \right) + \partial_x \left( m, Huv \right) + \partial_y \left( m, m, wv \right) + \left( mf + v \partial_x m, -u \partial_y m \right) H = \nabla \left( m, \frac{A}{H} \right) + Q.
\end{align*}
\]

(2)
\[
\frac{\partial p}{\partial t} = -gH(\rho - \rho_0)p_0^{-1} = -gHb
\]

Continuity equation is:

\[
\frac{\partial}{\partial t}(m\xi) + \frac{\partial}{\partial x}(mHu) + \frac{\partial}{\partial y}(mHv) + \frac{\partial}{\partial z}(mw) = 0
\]

\[
\frac{\partial}{\partial t}(m\xi) + \frac{\partial}{\partial x}\left[mH\int_0^1 udz\right] + \frac{\partial}{\partial y}\left[mH\int_0^1 vdz\right] = 0
\]

State equation is:

\[
\rho = \rho(p, S, T)
\]

Where \(H\) is the total depth, \(H = h + \xi\), \(h\) is the average sea level (Yellow sea elevation) distance to the seabed, \(\xi\) means the instantaneous water level; \(u, v, w\) velocity components were fitted borderline orthogonal curvilinear coordinates, \(x, y, z\) direction; where \(m = m_x m_x m_x\) and \(m_y\) are the diagonal elements of the metric tensor The square root; \(m\) is the square root of the determinant of the metric tensor; \(f\) is the Coriolis number; \(g\) is the acceleration of gravity; \(p\) is the pressure; \(A_v\) is the vertical turbulent viscosity coefficient; \(Q_u, Q_v\) respectively \(x, y\) direction momentum sink term; \(\rho\) is the mixed density; \(\rho_0\) is the reference density; \(S\) is the salinity; \(T\) is the temperature\(^{[6,8]}\). Salinity of the equation \(S = 0\), and assuming that the water is an incompressible fluid, the density \(\rho\) and the temperature \(T\) is constant.

2.2 Poyang Lake hydrodynamic modeling methods and data sources

By using remote sensing images during flood period of Poyang Lake in 1998 as a reference and combining with GIS data of levee in Poyang Lake, the maximum extent boundary of Poyang lake was determined, and on this basis, Poyang Lake was meshed by using orthogonal curvilinear grid, the total number of grids is 96004, the resolution of grids is between 178m and 205m, and the orthogonal grid parameter is less than 0.2. The DEM of Poyang Lake was provided by Hydrology Bureau of Jiangxi Province, which was measured in 2010 with a map scale of 1:10,000. The upper boundary of the model is daily measured flow data in Qiujin, Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan and Dufengkeng station (m\(^3\)/s), the low boundary is daily measured water level data in Hukou station (m, yellow sea height)(fig.1). The judgment parameters of dry-wet in the model are: water depth of dry grid is 0.16m, time step of dry grid is 16s.
2.3 Choice of typical years and calculation of lake area

2005, 2006 and 2010 is affirmed respectively as normal, dry and wet hydrologic year by Hydrology Bureau of Jiangxi Province in 10 recent years[7], therefore, in this paper, they are regarded as typical years for normal, dry and wet hydrologic situation.

Daily dry-wet status of every computational grid in typical years can be simulated by established Poyang Lake hydrodynamic model, in which dry-status means grids without water while wet-status presents grids with water. Therefore, the total water surface area of Poyang Lake, which will be used in subsequent analysis of this article, can be gotten by accumulation of each wet-grid area.

3 Analysis of the statistical relationship between water level and surface area in typical years

The daily lake surface areas in typical years (2005, 2006 and 2010) can be obtained by using hydrodynamic model of Poyang Lake. In order to compare mutual relationships between water levels and lake surface area in upstream and downstream of Poyang Lake, and build representative regressive relation, which uses water level as independent variable, lake area as the dependent variable, Kangshan, Tangyin, Duchang and Xingzi were selected as four actual water level sites in different parts of upstream and downstream in Poyang Lake. Finally, the mutual relationships of water level and lake area in wet, normal and dry hydrologic year were analyzed with daily simulated surface area and actual water level in above-mentioned years.

3.1 Analysis of the relationship in dry hydrologic year

Through curve regression analysis between the actual water and simulated area of Poyang Lake in 2006 (dry...
hydrologic year), the relationships between water level and lake area of Kangshan, Tangyin and Xingzi present a cubic equation, Duchang is quadratic equation (see Figure 2). The Curve regression relationships can be expressed as following:

\[ y_{\text{Kangshan}} = -134.73 - 67.77x + 1.16x^2 \]  \hspace{1cm} (7)

\[ y_{\text{Tangyin}} = -6494.03 + 780.93x - 0.6x^2 \]  \hspace{1cm} (8)

\[ y_{\text{Duchang}} = 134.92 + 139.12x + 4.53x^2 \]  \hspace{1cm} (9)

\[ y_{\text{Xingzi}} = 868.72 + 16x - 0.353x^2 \]  \hspace{1cm} (10)

Fig. 2 The relationship between water level and area in dry hydrologic year
The figure 2 shows, the correlation of water level and lake area of four sites have some differences. From the space perspective, northern sites correlation is better than that in the south of lake. The correlation coefficient of Kangshan, Tangyin, Duchang and Xingzi is 0.746, 0.907, 0.952 and 0.953 respectively, the correlation of the Xingzi station is best, and Kangshan station is relatively poor, but all of them show strong correlation in 0.01 level (bilateral).

The North-South differences of the correlation of water level and surface water area mainly relates to the terrain of Poyang Lake and the hydrological characteristics of “High water level like a lake and low water level like a river”. Inflowing rivers of Poyang Lake are mainly distributed in the south of lake. The terrain of lake in South is higher than that in North leads to the annual variation of southern sites (such as Kangshan) is less, and northern sites (such as Xingzi, Duchang and so on) is larger. When the water level variation of downstream (north of lake) or the heartland of lake does not affect the water level of upstream, the water level of sites in south can not reflect the water level and area of lake. In this situation, the error is greater.

As can be seen from the figure 2, when the area of Poyang Lake is 1400km² to 1600km², 2800km² to 3000km², there is a obvious phenomenon that there are several water area at the same level of each site, this phenomenon also affect the correlation of water level and water area in to some extent, which is relate to the process of ‘swelling’ or ‘recession’. That is the lake area corresponding to the process of ‘lifting’ is different at the same level. Because the paper length, the statistical relationship of water level and lake area in the process of ‘lifting’ will be discussed in subsequent papers.

3.2 Analysis of the relationship in normal hydrologic year

Similarly, curve regressions of actual water level and simulated surface area of Poyang Lake in 2005 (normal hydrologic year) are analyzed, the results show, statistical relationship of actual water level and simulated surface area in Tangyin, Duchang and Xingzi station can express as cubic relation, while Kangshan station shows as quadratic relation. The statistical equation of Kangshan, Tangyin, Duchang and Xingzi station in normal hydrologic year can be shown as follows:

\[
\hat{y}_{\text{Kangshan}} = -313.81 - 151.95x + 23.33x^2
\] (11)

\[
\hat{y}_{\text{Tangyin}} = -8463.76 + 1002.11x - 1.04x^3
\] (12)

\[
\hat{y}_{\text{Duchang}} = -970.72 + 297.91x - 0.13x^3
\] (13)

\[
\hat{y}_{\text{Xingzi}} = -168.36 + 222.16x - 0.03x^3
\] (14)
Fig. 3 The relationship between the water level and area in normal hydrologic year

The figure 3 shows, the overall trend of the relationship of actual water level and simulated area is similar to dry hydrologic year in the four stations, the correlation also increases progressively from south to north. Pearson correlation coefficient of Kangshan, Tangyin, Duchang and Xingzi station is 0.579, 0.888, 0.951 and 0.936 respectively, the verification of correlation coefficient shows, except Kangshan station, the other three stations also show strong correlation and are significantly associated at the 0.01 level (bilateral), correlation of Duchang station is the most obvious.

Compared with dry hydrologic year, there is more affluent inflow into the lake in normal hydrologic year, which results in the variation of water level of Poyang Lake being larger than that of dry hydrologic year. Therefore, the variation of surface area of Poyang Lake is also larger. Similarly, owing to the higher ground of southern stations (e.g., Kangshan station), its amplitude of water level in wet, normal and dry hydrologic year is smaller than that of lake district, thus the correlation of actual water level and simulated area of southern stations is poorer than dry hydrologic year. The process of ‘lifting’ in normal hydrologic year is stronger than that in dry hydrologic year, resulting in the variation of corresponding surface area of Poyang Lake being also larger in the same condition. It can be clearly informed from figure 3 that the plots is more scattered than those in dry hydrologic year when the area of Poyang Lake is in 2, 000km$^2$ to 2, 500km$^2$ or 3, 000km$^2$, and it indicates the corresponding relationship of water level and surface area is more complex.
3.3 Analysis of the relationship in wet hydrologic year

The statistical relationships for water level and lake area of Kangshan, Tangyin, Duchang and Xingzi present Cubic equation, and coefficient of determination ($R^2$) is close to 1, according to the curvilinear regression analysis for 2010 year (wet hydrologic year). The statistical relationship is as follows:

\[
y_{Kangshan} = -15332.27 + 1558.51x - 1.58x^3
\]  
\[
y_{Tangyin} = 8728.88 + 1028.5x - 1.08x^3
\]  
\[
y_{Duchang} = -1326.94 + 352.67x - 0.26x^3
\]  
\[
y_{Xingzi} = 1326.71 - 208.13x + 41.1x^2 - 1.27x^3
\]

As can be seen in Figure 4, the curve overall trend of the actual water level and simulated area is similar to that in dry, normal hydrologic year. The correlation coefficient of Kangshan, Tangyin, Duchang and Xingzi is 0.745, 0.924, 0.960 and 0.962 respectively and passed the significance test at 0.01 level (bilateral). The correlation of Xingzi station is the most obvious.

Fig. 4 The relationship between water level and area in wet hydrologic year
Due to inflow into lake is most plentiful in wet hydrologic year, the lake water level amplitude is largest. The southern sites of higher ground that are greatly affected by water level of Poyang lake present the same trend as the change of surface area. Consequently, the relationship between water level and lake area is approximately the same as that in dry hydrologic year.

4 Result verification

To verify the relationship of actual water level and simulated area of Poyang Lake, 6 scenes of remote sensing images of Landsat 7 ETM are downloaded respectively in some days of 2005, 2006 and 2010, in which days water level is in the medium and lower level. The actual surface areas of Poyang Lake are calculated by ArcGIS software using remote sensing data.

Table 1 The error with the actual and estimated area

| Date      | The estimated area (km²) | The actual area (km²) | Absolute error | Relative error |
|-----------|--------------------------|-----------------------|----------------|----------------|
| 2006-2-4  | 1555.30                  | 1581.52               | 26.22          | 1.66%          |
| 2006-2-20 | 1547.03                  | 1534.07               | 12.96          | 0.84%          |
| 2005-4-14 | 2029.13                  | 2024.28               | 4.85           | 0.24%          |
| 2005-4-30 | 2053.05                  | 1782.58               | 270.47         | 15.17%         |
| 2010-9-19 | 3059.43                  | 3099.01               | 39.58          | 1.28%          |
| 2010-10-5 | 2776.64                  | 2943.91               | 167.27         | 5.68%          |

Table 1 lists the imaging time of six scenes ETM and the corresponding actual surface areas calculated by remote sensing data. Statistical relationship between water level and surface area in different years are established, using water level in the imaging time of remote sensing data as the independent variable, and plugging it into statistical equations of water level and surface area that has been established, lake surface area can be deduced. Table 1 also lists estimated surface areas. By contrasting the two areas, errors between simulated areas and actual areas are assessed. Table 1 presents absolute errors and relative errors of actual areas and simulated areas respectively, while figure 5 presents the contrasted schematic diagram of two areas. It is noteworthy that the correlation in Duchang station is relatively stronger, therefore the simulated areas in table 1 is estimated by statistical equation of water level and surface area in Duchang station.

![The actual size comparison chart with the estimated area](image)
From the table 1 and figure 5 it can be seen that the error between estimated area and actual area of Poyang lake in dry, normal and wet hydrologic year, and the absolute error is in 4.85km² to 270.47km², the relative error in 0.24% to 15.17%.

Since cloudy and rainy during high water level, the remote-sensing images without cloud in the Poyang Lake are difficult to obtain. In the error analysis, there are no any remote-sensing images to be used to verify the estimated area of Poyang Lake during high water level.

5 Conclusion and discussion

Based on hydrodynamic model of Poyang Lake, the lake area of day by day in 2005, 2006 and 2010 year (typical normal, dry and wet hydrologic year) were simulated in this paper. By analyzing the statistical relationships between lake area simulated and measured water level from the different positions of the four lakes (Kangshan, Tangyin, Duchang and Xingzi), The Statistical equation, which is obtained by using the water level to estimate lake area of the four sites in Poyang lake, was built.

Results indicate that there were positive correlations between the water level and area. The average correlation between the water level and lake area of Duchang site in dry, normal and wet hydrologic year is stronger. At the time of estimated the lake area by the measured water level, the statistical equations between water level and lake area in Duchang can be used. The statistical equations in dry hydrologic year is: \( y_{\text{Duchang}} = 134.92 + 139.12x + 4.53x^2 \); The statistical equations in normal hydrologic year is: \( y_{\text{Duchang}} = -970.72 + 297.91x - 0.13x^3 \); The statistical equations in wet hydrologic year is: \( y_{\text{Duchang}} = -1326.94 + 352.67x - 0.26x^3 \).

Because of the error being relatively large, in the period of simulating low water level by Poyang Lake hydrodynamic model, the error of simulated area is relatively large. In this case, there must be some errors when the established equation is used to estimate the relationship between the actual water level and the lake area. Therefore, the surface area calculated from the actual water level exist uncertainty especially during the low water level. However, it is noteworthy that the established equation is in accord with statistical law relatively, due to high temporal resolution of simulated surface area data. In conclusion, there is a scientific significance.

The built equations for estimating lake surface area only represent overall relations between water level and area of Poyang Lake in one year, in fact, through above mentioned analysis, the overall relations of water level and surface area of Poyang Lake also contain many secondary relationships in different processes of ‘lifting’, and these relations lead to the obvious phenomenon that different surface areas of Poyang Lake corresponding to the same water level. To build more elaborate and accurate relationship of water level and surface area, it is necessary to explore interrelation of that in different process of ‘lifting’. The details will be dealt with in the further study because of the paper length.

References

[1] Chen, J., Zhao, W., and Ji, Z., 2005, Chongqing Liang Jiang Hui water dynamic model, Hydrodynamics Research and Development (A Series), S1, 829-835

[2] Ding, Z., 2010, Study Reservoir water area of the curve measurement method combining DEM and remote sensing, Water Conservancy and Hydropower Engineering, 01, 83-86
[3] Gan, Y., Li, L., and Wu, J., 2013, Temperature simulation and temperature stratification affect EFDC based Ertan Reservoir, Resources and Environment in the Yangtze Basin, 04, 476-485

[4] Lei, S., Zhang, X., and Xu, X., 2010, Based remote sensing technology to monitor and analyze the dynamic Poyang Lake water area and volume, Water Conservancy and Hydropower Engineering, 11, 83-86 +90

[5] Li, R., Zhu, Y., and Zheng, J., 2003, Humen Taiping waterway regulation project tide modulus calculation, Waterway engineering, 03, 38-42

[6] Liu, F., Zhang, X., and Fan, J. 2011, to improve the water level of Poyang Lake water area and Hukou relational model, Meteorology and Disaster Reduction Research, 04, 45-49

[7] Lu, H., Ni, W., and Yuan, Y., 2013, Calculation is based on an artificial lake ecological water changes to optimize EFDC model, Hydroelectric Energy, 04, 100-102 +133

[8] Ma, Y., Xiong, C., and Yi, W., 2003, Poyang Lake Sedimentation characteristics and development trend, Resources survey and environment, 01, 29-37

[9] Pan, X., Wang, W., and Tang, j., 2010, hydrodynamic and water quality modeling study Hada Mountain Reservoir, Peoples of the Yellow River, 08, 61-62

[10] Xie, R., Wu, D., and Yan, Y., 2010, EFDC model development in the Yangtze River Estuary and adjacent waters of the three-dimensional flow simulation, Hydrodynamics Research and Development Series A, 02, 165-174

[11] Zhang, N., Wang, W., and Wang, Y., 2012, Satellite remote area of Poyang Lake water level estimation and analysis and the relationship, Sensing Technology and Application, 06, 947-953

鄱阳湖典型年份水位与面积关系的模拟研究

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摘 要：鄱阳湖是中国最大的淡水湖泊，水位与面积是湖区生态系统中的重要参数。为了探求鄱阳湖区水位与面积的关系，根据鄱阳湖流域的边界数据，湖底地形数据及入湖五河七口在典型年份的水位数据，利
用美国 EFDC 水动力学模型对该区域进行模拟，而后根据康山，棠荫，都昌，星子四站实际水位与模拟面积建立数学关系，最后使用典型年份遥感数据对实际面积与模拟面积进行验证。结果表明，典型年份鄱阳湖水位与面积具有高动态性，模拟面积与实际面积误差较小。

关键词：鄱阳湖；EFDC；水位；面积；数值模拟
城市发展与湖泊水环境保护探讨
—以江西省九江市为例

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摘 要：城市湖泊是城市的重要组成部分，具有蓄水、防洪、生态、景观等多种功能，而城市建设与扩张对城市湖泊带来的负面影响不可忽视。本文以九江市为例全面阐述了城市发展过程中应重视湖泊水环境的保护，并提出了相应对策与措施。

关键词：城市发展 湖泊 保护对策

中国幅员辽阔，湖泊众多，其中面积1km²以上的湖泊有2700个，总面积在9万km²以上，自人类社会诞生以来，湖泊与城市相伴相生。九江市城区河流湖泊众多，主要湖泊有赛城湖、八里湖、甘棠湖、南湖、琵琶湖和白水湖；河流主要有十里河、濂溪河、沙河，其中濂溪水在九江职业技术学院附近汇入十里河，十里河水最终流入八里湖，八里湖通过闸口调节，其水流入长江。见图1。

水是生命之源，城市依水而建，城市河湖的水环境影响着整个城市人口的生活质量，也体现一座城市的文化品位。甘棠湖、南门湖位于九江市中心，2009年初，九江市作出将城市建设的重点从“两湖”（指甘棠湖、南湖）向八里湖转移的战略决策，从而八里湖新城区建设便如火如荼，现已初具规模。九江市建成区面积由2005年的49.3km²，发展到2009年的89.47km²，规划到2020年建成区面积将达120km²，可见城市建设的速度之快、规模之大。
1 城市湖泊的主要功能

无论是天然湖泊还是人工湖泊，他们都是城市的重要组成部分，与城市居民的生活密不可分。总体来说，城市中湖泊的功能主要体现在以下几个方面：

1.1 涵养水源

湖泊是地表水体的一种，由地势低洼处的积水形成。湖水接纳湖区降水，入湖河流及周边浅层地下水作为补给，把水截留在湖体内，改善了地表水和浅层地下水的水文状况，调节区域水循环，保护水分不流失。湖泊特别是大型湖泊是城市水资源的主要载体，在平衡水量、削洪补枯、调节区域小气候等方面发挥着重要作用。九江市城区湖泊众多，人工水体下约有 $4.05 \times 10^8$ m$^3$ 蓄水量。其中赛城湖的蓄水量约 $2.33 \times 10^8$ m$^3$，为九江市城区应急水源。

1.2 调蓄洪水

城市湖泊具有一定的调节库容量，能在暴雨来临后迅速接纳降雨造成的地表径流，贮存暂时不能排除出去的洪水，减轻城市的雨洪压力。如，九江市的八里湖主要接庐山西北面各支流坡面汇流，集水面积为 273 km$^2$，湖水位 22 m 时，水面面积约为 27 km$^2$，相应蓄水量为 $1.54 \times 10^8$ m$^3$。九江市城区湖泊众多，人工水体下约有 $4.05 \times 10^8$ m$^3$，其中赛城湖的蓄水量约 $2.33 \times 10^8$ m$^3$，为九江市城区应急水源。

1.3 景观旅游

湖泊因为拥有丰富的水面和湖滨带景色而成为人们休闲娱乐的最佳目的地之一。现代都市生活节奏快，压力大，在工作之外接近大自然是每个人的迫切需求；而且湖泊就是渴望回归自然的人们最理想的归宿。目前各个城市的管理层已经意识到了湖泊的景观旅游价值，纷纷把城市湖泊及其湖滨带建设成专门的公园、风景游览区或自然保护区，在对湖泊加强保护和管理的同时，也满足了人们的景观需求。如九江市的甘棠湖、南湖是江南著名的城市湖泊，湖中“烟水亭”据说曾是三国时周瑜点将台，湖中泛舟、湖边漫步和垂钓，为市民休闲的理想的场所，夜晚徜徉在湖滨、堤岸，如梦如幻的灯影有如仙境。

2 城市开发给湖泊带来的主要问题

城市湖泊与人类生产生活方式与环境密不可分，随着社会经济的发展，城市人口的增加，特别是城市化进程的加快，给城市湖泊带来了一些问题，湖泊所承载的压力更大。在水利部门监测的 120 个开发利用程度比较高、面积比较大的湖泊中，水质满足Ⅰ至Ⅲ类标准的只有 39 个，约占 32.5%。城市开发给湖泊带来的主要问题如下。

2.1 湖泊污染严重、富营养化加剧

自城市出现以来，湖泊一直作为城市排放污水的主要受纳载体。在产业革命之前，城市居民密度小，生活污水排放量少，依靠湖泊的自净功能完全可以净化城市污水，不至于造成严重的环境污染。进入城市化、工业化时代以后，部分工业废水未经处理被直接排放进湖泊，导致湖泊中积累了高浓度的有毒有机物、重金属等有害物质。沿湖居民的激增也给湖泊带来了空前的富营养化压力。九江市水环境监测中心每季对城区湖泊监测一次，九江市城区湖泊中仅赛城湖的水质达标，其他湖泊的水质较差，富营养化程度以中度为主。

2.2 城市建设与湖泊保护的矛盾未能较好解决

规划是湖泊保护的基础和依据，对湖泊进行规划保护是根本性的保护。湖泊犹如城市的眼睛，具有无
法估量的生态价值。然而，长期以来城市开发中缺乏一个合理有效的湖泊保护生态规划，从而造成了湖泊开发利用的无序化，湖泊保护工作各行其是，甚至将湖泊保护与城市开发对立起来，缺乏城市生态系统的整体观念。

2.3 城市湖泊管理体制混乱、权属不清

长期以来，城市湖泊的管理权往往隶属于不同的行政机构，有的湖泊通过承包等方式交由多个部门开发，导致湖泊使用权属混乱，管理职责重叠交叉，权责不清，责任不明晰。九江市城区湖泊管理同样存在多头管理的问题，水利、建设、旅游、水产等部门各行其是。

2.4 湖泊景观破坏

城市湖泊被人为围填、污染，破坏了湖泊原有的自然景观，甚至会影响到城市整体形象。某些长期缺乏妥善保护的小型湖泊（水塘），其护岸破坏，湖水黑臭，湖面漂浮着垃圾，不仅没有满足附近居民景观休闲娱乐的需求，还因恶劣的环境和不堪的景象影响到居民的身体和心理健康。部分已经被保护起来并被辟为风景区和公园的湖泊，由于用地的限制，其护岸大多是用浆砌石、混凝土等材料构成的硬质直立护岸，无自然过渡和岸线变化，显得呆板僵硬。最近几年，九江市城区湖泊管理同样存在多头管理的问题，水利、建设、旅游、水产等部门各行其是。

2.5 湖泊萎缩、消失

土地是城市发展的基本要素，也是城市中最稀缺的资源，基于这个原因，大部分城市湖泊长期以来一直处于被城市建设用地逐步蚕食的困境。近几十年来，因为城市建设而被围填甚至完全消失的湖泊不在少数。曾经有“燕京新八景”之称的北京太平湖，在1971年北京修建地铁时被填平，原址上建成地铁检修车辆段。20世纪90年代以来的开发热使武汉市城区35个湖泊被填占了3.14km²，有8个湖泊已经在地图上消失。九江市八里湖自2009年以来，修建了几条沿湖公路、架设了八里湖大桥，为下一步八里湖新城区建设打下了良好的基础，但也填占了部分湖面。

3 城市湖泊保护对策

城市中的河流湖泊是城市发展的命脉。作为城市的生态载体，城市河流湖泊直接反映着城市人居环境的好坏，影响着城市的形象与地位，对传承城市历史文化起着非常重要的作用，是城市文明之源。同时城市河流湖泊的综合性、多层次的社会服务功能，为城市发展奠定了坚实基础。在城市开发过程中应把河流湖泊的保护放在突出位置。

3.1 城市规划中应考虑城市湖泊的保护

城市规划是城市未来发展的蓝图，科学合理的城市规划是有效保护城市湖泊的法理依据。从功能区划上来说，湖泊应该定位为城市重要的水资源涵养地、景观娱乐休闲地、多样性生物栖息地。因此，在进行城市规划前，应先做好城市河流湖泊保护规划，本着尊重自然、顺应自然、保护自然的理念做好城市河流湖泊的保护规划。应在湖泊和附近城市建设用地之间留有足够的缓冲空间，适当放宽绿线，严格限制湖区周边房地产开发项目，限制建筑物高度和体量。对城市湖泊的规划不能仅仅针对单个湖泊，更应该把城市河湖水系作为一个有机整体来统筹安排，实现湖与湖之间、湖与河之间良性连通，打造一个全面健康发展的城市生态水系。九江市在八里湖新城区规划中非常注重湖泊保护，坚持打造一个生态新区的目标，做到
基础设施和公共服务设施两个优先，按照三分之一的水面、三分之一的森林和树木、三分之一的建筑规划布局，营造观湖、观江、观山、观城生态效果来高标准建设八里湖新区。

3.2 研究湖泊的承载能力，不断削减负荷直到湖泊达标

在不损害环境功能的前提下，湖泊所能接纳的污染物的最大允许输入量即是湖泊环境容量。它与湖泊容积大小、水流交换速度、水生生物种类及污染物本身性质有关，是湖泊水质管理的重要参数。湖泊能承受的污染是有限的，当污染物大量入侵，湖泊水质受到严重污染时，湖泊的环境容量就会出现超载，湖泊功能丧失。为科学有效在保护湖泊，应该计算每个湖泊的承载能力，从而削减负荷，恢复湖泊主要功能。

九江市水环境监测中心 2011 年对八里湖开展了为期一年的水质监测与研究。根据九江市水功能区划，八里湖一级区划为开发利用区，二级区划为景观娱乐用水区，水质目标为Ⅳ类水，表 1 是八里湖纳污能力计算成果。

从表 2 可以看出，通过对八里湖限制排污总量和现状污染物排放量的分析，八里湖的入湖削减量为：COD220t/a，氨氮0t/a，总氮 65.66t/a，总磷 4.287t/a。十里河、沙河是流入八里湖的主要河流，政府及有关部门可根据氨氮、总磷、总氮的削减量去进行有针对性的治理。

表 1 八里湖纳污能力统计表

| 参数               | COD  | 氨氮 | 总氮     | 总磷   |
|-------------------|------|------|----------|--------|
| 现状排污量（t/a） | 2312 | 123.7| 65.66    | 9.630  |
| 纳污能力（t/a）   | 2092 | 145.4| 0        | 5.343  |
| 限制排污总量（t/a）| 2092 | 145.4| 0        | 5.343  |
| 入湖削减量（t/a） | 220  | 0    | 65.66    | 4.287  |

3.3 整治入湖河流，从源头上保护湖泊水质

只有彻底切断污染源，才能从根本上保证湖泊水环境不再继续恶化下去。应当封堵湖泊周围和入湖河道的所有排污口，沿湖沿河修建截污管道或改造原有污水排放系统，把污水输送到城市污水厂进行处理。恢复湖滨自然植被带，通过种植湿地植物和护坡草皮，减轻面源污染所带来的危害。定期打捞湖泊和入湖河道上漂浮的垃圾，定期清理底泥，消除湖泊线源和内源污染。

十里河、沙河是八里湖的主要水源，由于十里河、沙河来水水质较差，因而造成八里湖的水质较差。九江市水环境监测中心 2011 年 3 月、7 月、10 月在十里河入湖口、湖北、湖中、湖南、出湖口布设五个监测点，监测氨氮、COD、总磷、总氮、重金属铜五个项目。3 月是枯水期，环境容量小，十里河入湖口氨氮 1.44mg/L、总磷 0.125mg/L，对照《地表水环境质量标准》(GB3838-2002)，氨氮、总磷属 V 类，铜属劣 V 类；7 月来水量大，各监测点水质相对较好；10 月来水量减小，各监测点水质相对变差。沙河入湖口、出湖口及湖中其他监测点的水质与来水量大小的关系与十里河基本一致。但无论是枯水期还是丰水期，八里湖的水质总体较差。

十里河来水对八里湖水质的影响很大，为改善八里湖水质和打造十里河生态环境，九江市从 2009 年起，开始对十里河进行整治，据统计，全程拆迁 18 万 m²，开挖土石方 200 余万 m³，河道清淤 40 万 m³，新建钢坝 4 座、改建和新建桥梁 16 座、埋设截污管道 16.6Km，将十里河及八里湖打造成集防洪、环境、生态、
景观为一体的、多功能的环境工程；沙河的整治也正在进行。通过对十里河、沙河的整治，八里湖的水质将会逐步得到好转。

3.4 理顺湖泊管理权属

城市湖泊环境恶化在很大程度上是由于缺乏有效的管理造成的，因此加强管理对湖泊的保护来说显得格外重要。需要当地人大、政府制定出湖泊保护的相关法律条文，使城市湖泊保护和管理做到有法可依，如出台《九江市城市河流湖泊保护条例》等。对管辖范围内的湖泊进行清理，湖泊的管理权由政府指定一个部门统一行使，其他有关部门配合。湖区的日常管理维护工作也必须严格执行，包括生活垃圾清理、公共设施维护、安全隐患检查以及植物浇灌栽种和水生动物投放等。

3.5 加强湖泊水质监测、提高市民保护湖泊的意识

环境保护及水行政主管部门应定期对城市湖泊进行水质监测，查找污染源，提出解决办法，及时通报湖泊水质状况，让政府及社会各界了解湖泊水质现状。九江市水环境监测中心把城区河流湖泊水质监测列入了常规监测体系，每季度监测一次，并发布《九江市城市河湖水资源质量监测通报》。

民众是湖泊资源的享用主体，湖泊的众多功能直接或间接是向广大民众提供服务的，如果没有民众自觉保护意识的提升，即使政府实施的管理再好，湖泊保护从根本上也无法得到保证。加强民众的湖泊保护意识，使民众对自己的不当行为加以约束，积极参与到保护湖泊的行动中来，是湖泊保护对策的重要组成部分。政府部门要大力宣传保护政策，普及科学的环境保护知识，加深民众对湖泊价值和功能的认识，在民众中形成一种自觉保护湖泊的思想意识和责任感，培养良好的保护习惯，构建和谐的人、湖关系。

3.6 创建生态文明城市

九江市城区有长江、八里湖、十里河等水体，水面面积约 110 km²，具有良好的水生态环境，是江南名城，文化底蕴深厚。生态文明建设已经成为国家战略，通过创建生态文明城市，把九江打造成有足够森林绿地、足够江河湖面、足够自然生态的山水城市；构建人水相依、宜业宜居宜游的城市环境，提高九江的城市品味。

参考文献:
[1] 张雅卓. 城市河道综合整治研究及思考[J]. 水利发展研究. 2009. (6): 32—37.
[2] 代银萍. 九江市城区河湖水质现状及污染防治措施[J]. 江西水利科技. 2010. (1): 11—14.
[3] 姜付仁等. 广州市城市排涝经验与启示[J]. 水利发展研究. 2012. (3): 20—23.
[4] 涂明等. 谈《南昌市城市湖泊保护条例》的实施[J]. 江西水利科技. 2010. (1): 72—77.
A discussion of urban development and water environment protection of lakes - Taking Jiujiang, Jiangxi as an example

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Abstract: Urban lakes are an important part of cities, with a variety of functions such as water storage, flood control, ecology, landscapes and so on, while the negative effect on urban lakes caused by urban construction and expansion cannot be ignored. This paper, by taking Jiujiang City as an example, makes a comprehensive exposition that water environment protection of lakes should be taken seriously during the process of urban development, and puts forward the corresponding countermeasures.

Keywords: Urban development; Lakes; Protective countermeasures
促进绿色旅游与鄱阳湖生态建设和谐发展

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摘 要: 鄱阳湖生态经济区建设是江西省转变发展方式，探索生态与经济协调发展新路子的一项重要战略举措。鄱阳湖生态经济区自然环境优越，有着丰富的生态旅游资源，厚重的历史文化底蕴。本文从江西省情出发，分析我省科学发展、绿色崛起所具备的条件和环境，围绕促进绿色旅游与鄱阳湖生态建设协调发展的主题，就如何发挥绿色生态优势和贯彻旅游强省战略进行研究与探讨，阐述了生态资源对于江西经济发展的重要意义，提出了发展鄱阳湖绿色旅游的途径、措施以及如何保护鄱阳湖生态的思路和建议。

关键词: 鄱阳湖生态经济区；生态环境；绿色旅游；生态保护

在全国经济转型的形势下，江西经济应如何找准位置，发挥后发优势，超速发展?如何从本省实际出发，瞄准发力点，下好赶超棋?从世界的格局来看，多数先进国家都在发展高新科技、发展创新型经济。从国内来看，经过前期经济高速发展之后，现在进一步调整经济结构，切实提高经济发展质量和水平。纵观国际、国内的形势和发展趋势，江西经济发展亦应转变思路，顺势而为，认清省情，仔细分析自己的优势和劣势、可能性和现实性。必须深刻认识到，良好的生态环境是江西最大的特点、最强的优势、最深的潜力，也是推进江西科学发展、绿色崛起的途径所在。党的十八大以来，江西省委省政府提出“发展升级、小康提速、绿色崛起、实干兴赣”的工作思路，围绕构建新型农业经营体系、实施工业强省战略、推进旅游强省建设等出台了一系列产业发展规划和意见，进一步明确了江西经济发展的主攻方向。

生态是江西最大的优势，绿色是江西最亮的品牌。加快鄱阳湖生态经济区建设，必须突出重点，明确抓手。绿色旅游，就是重点，也是抓手之一。顾名思义，绿色旅游就是生态旅游，也是文化旅游，又是智慧旅游。按照生态与经济协调发展的要求，在鄱阳湖生态经济建设过程中，努力构建以生态农业、新型工业和现代服务业为主要内容的环境友好型产业体系。绿色旅游是最优质、最相宜的友好型产业，它对鄱阳湖生态的负面影响最小。鄱阳湖生态的优化和发展，是江西绿色旅游的名片和支撑；而绿色旅游的发展，又能进一步树立鄱阳湖经济生态区的品牌，促进鄱阳湖生态经济的发展。
充分认识生态资源对江西经济发展的深远意义，加快发展绿色旅游的步伐

由于各种原因，江西经济在改革开放初期发展相对滞后，特别是工业经济基础比较薄弱。但换个角度来看，江西环境污染小，自然生态保护较好，森林覆盖率居全国前列。这为生态经济发展、绿色旅游壮大打下了良好基础。这种优势是金钱换不来的，也不可能短时间内一蹴而就，我们必须明白这种优势，清醒认识优势，珍惜眼前的宝贵生态，重点保护，善加利用。这里，我们从经济发展程度不同的地区可以得到深刻启示。

例一，据报载，地处华北的某能源消耗大省，每年消耗全国1/12的能源，创造的是1/20的GDP，1/34的财政收入。为了调整产业结构，化解过剩产能，治理大气污染，当前正在经历一场伤筋动骨的压缩产能过程：到2017年压缩钢铁产能6000万吨，水泥6000万吨，煤炭6000万吨，玻璃3000万标准箱。该省痛切认识到，生态环境对于自身发展和责任担当等方面都是“命门之穴”，为此提出坚定不移走“绿色崛起”之路。

例二，地处西北的某中心城市，生态环境优势并不明显，近几年，该市在广泛综合国内外城市发展基础上，创新发展思路，设立了生态型城市新区——浐灞生态区，通过对河流的综合治理和流域的生态重建，改善生态环境，提升城市综合承载力。截止目前，生态区湿地面积由2005年的586公顷增加到现在的1266公顷，生态区内湿地覆盖率由2005年的6.6%增加到13.2%，成为渭河乃至黄河下游最重要生态屏障和水源涵养地，也带动了新城区区域价值的提升。

综上可知，不管是为偿还历史“欠账”去治理生态环境，还是先天条件不足而后天大力改善生态环境，大家都日益认识到，生态资源始终是经济发展的先决条件。只有生态资源健康，经济发展才是可持续的。为了发展经济而忽视环境恢复的保护，即使经济一时有了高速增长，到头来治理的费用是高昂的，治理过程是漫长的，偿还“欠账”是费力的。现在无论是谈绿色GDP，还是绿色崛起，核心都是保护生态环境。

江西生态环境质量位居全国前列，气候温和，雨水充沛，森林覆盖率达63.1%，全省地表水监测断面水质达标率为80.8%，高出全国平均水平30多个百分点，主要河流监测断面保持在II类水质。全省建成自然保护区188个，其中国家级自然保护区13个。不仅如此，江西文化底蕴在全国也是屈指可数，陶瓷文化、宗教文化、客家文化、书院文化等在世界上都有重要影响，红色文化更是独树一帜。江西成为度假胜地，养生福地，旅游首选之地。利用良好的生态资源，以及厚重的文化资源，大力发展绿色旅游，是江西经济发展的重大课题。

近年来，全球旅游市场稳健增长。据世界旅游组织预测，到2020年亚洲旅游市场国际游客接待量占全球比重的30%。在我国，居民旅游消费意识迅速觉醒，消费能力快速增长，旅游业发展进入了黄金时代，也为江西旅游业发展带来新的机遇。近几年江西旅游业发展迅猛，亮点频出，成绩喜人。“江西风景独好”反复在各种媒体宣传，在全国产生了巨大反响，旅游人数节节攀升。2013年江西旅游接待总人数达2.5亿人次，同比增长22%，旅游总收入达1896.06亿元，同比增长35.18%，直逼2000亿大关。江西的绿色旅游发展势头强劲，潜力巨大，后劲很足。

作为江西经济发展的龙头，鄱阳湖生态经济区建设已列入江西省规划、上升为国家战略。客观形势要求鄱阳湖生态保护走在前列，鄱阳湖绿色旅游走在前列。要总结和借鉴国内外生态环境保护的经验，确保青山长翠，绿水长流。在江西绿色崛起过程中，利用鄱阳湖
良好的生态优势，着力下好旅游强区这盘棋，抒写绿色旅游精彩华章。

鄱阳湖生态区拥有得天独厚的自然资源，为绿色旅游打下厚实基础

鄱阳湖位于江西北部，是我国第一大淡水湖，南北长 172 公里，东西最宽 74 公里，面积达 4000 平方公里。江西境内五大干流，赣江、饶河、抚河、信江、修河全部汇入鄱阳湖，通过湖口与长江相连。鄱阳湖拥有丰富的鱼类、鸟类等物种资源，是全球 95%以上的越冬白鹤栖息地，在保护全球生物多样性方面具有不可替代的作用，是我国重要的生态功能保护区，是世界自然基金会划定的全球重要生态区，是我国唯一的世界生命湖泊网成员，在我国乃至全世界生态格局中具有十分重要的地位。

鄱阳湖水域与鱼类、鸟类、湿地、草洲等，形成上下承接的生物链，草洲、湿地生长着众多种类植物和水草，为鱼虾贝类提供了丰盛的养料。而当候鸟来越冬时，则捕食湖区游浮栖息的鱼虾贝螺。各种自然生态层面互为需求、互相补充，自然和谐、天人合一，从而形成了一道完美的生态链和优美的风景线，为绿色旅游打下了坚实的基础。
僧慧远吟诗品茗、虎溪送客；李太白跋山涉水、仰望庐山，"飞流直下三千尺，疑是银河落九天"；登顶匡庐，苏东坡看见了另一番景象，"横看成岭侧成峰"；白居易谪居九江，浔阳月夜《琵琶行》……这里历史悠久、风景优美、空气清新、民风淳朴。相比九寨沟等成熟度较高的景区，这里原生态更为完整和浓郁。鄱阳湖生态区成为一块养在深闺的璞玉，等待人们去开发和探索。

3 发展鄱阳湖绿色旅游的途径和措施

旅游业被誉为朝阳产业、无烟产业，结合鄱阳湖生态区优质的空气、纯净的水质、优美的环境，绿色旅游是最具条件率先崛起的产业，将成为鄱阳湖生态区乃至全省经济发展的新引擎、新动力。当前发展鄱阳湖绿色旅游，主要应该采取以下措施：

（1）制定科学合理的鄱阳湖绿色旅游规划，高位推动，规划先行。

科学而合理的规划是成功的基础和前提，借助科学的规划，可以避免走弯路。要广泛吸收国内外优秀成果，借助一流的咨询机构，依据国务院正式批复的《鄱阳湖生态经济区规划》，省委省政府的《关于推进旅游强省建设意见》，从鄱阳湖生态区实际出发，高起点、高视觉，制订和完善鄱阳湖绿色旅游规划。规划要具有超前性，应整合资源，高位推动，错位发展，充分发挥独特优势，发挥后发优势，发挥整体优势，推动鄱阳湖绿色旅游进一步发展。

（2）精心筹划鄱阳湖绿色旅游，制定丰富多样、富有特色游览线路。

让不同的游客有适合的旅游选择，让每次到鄱阳湖旅游都有新的收获和喜悦。要制定丰富而有特色的旅游方案和线路，如鄱阳湖湖湿地与候鸟观赏之旅、鄱阳湖沙山露营野趣之旅、鄱阳湖古村寻幽探秘之旅、鄱阳湖湖底古城科考之旅、鄱阳湖书院寺庙静修之旅、鄱阳湖药谷药都保健之旅等等。

（3）结合鄱阳湖绿色旅游，进一步拓宽和延伸产业链。

加快推进旅游产业与其他产业的深度融合，形成多元化旅游业态群。充分利用鄱阳湖优质水产资源，大力发展食品加工产业；利用周边特色产业、产品，打造陶瓷文化、稻作文化、中药文化、茶文化等文化产业；围绕绿色旅游，大力发展生态农业，让绿色农产品走上游客餐桌，走进游客背包，走向全国四面八方。进一步发展休闲农庄、休闲农院经济等。

（4）发展鄱阳湖绿色旅游，必须进一步拓深智慧旅游。

旅游已经开始从最初"傻瓜式"跟团游变为"攻略式"自由行，人们开始呼唤一场"说走就走"的旅行。为将绿色旅游更好服务游客，推进纵深发展，智慧旅游是必行。新一代信息技术在旅游业的具体应用，使游客吃、住、行等可以在网上预订、网上支付。动一动"拇指"就能下单，"私人订制"旅游线路。利用信息技术，更好的引导游客错峰旅游、自由选择时间、自主选择线路，方便接受咨询投诉、改进服务。只需一部手机，就能体验吃、住、行、游、购、娱的智慧旅游，已在鄱阳湖悄然启动。

（5）加强基础管理，下力气培养一支合格的旅游人才队伍。

绿色旅游的发展能否持续，关键在人，成败在人。要有目标、有计划、成规模的培养旅游各类人才，包括旅游管理、导游、司乘、特色餐饮等层面人员。加强服务意识教育，严格投诉率考核，不仅要留得住客源，还要通过良好的自身形象去影响和带来更多的客源，使广大游客在鄱阳湖、乐在鄱阳湖、以后常来鄱阳湖。要进一步加强旅游的基础设施建设，以
便民利游为宗旨，因地制宜的提高吃、住、行等方面的硬件水平。

4 保护好鄱阳湖生态是绿色旅游的命脉和存依所在

鄱阳湖生态区与绿色旅游是唇齿相依的关系，没有良好的生态，绿色旅游成为无源之水，无从谈起。因此，发展绿色旅游，建设鄱阳湖生态经济区，关键在生态，核心在生态。这就必须大力发展现代水利，支撑鄱阳湖生态区经济建设。大兴水利基础建设，构建调配有效的水利保障体系，进行有效的水土保持，科学的实施水资源管理、配置和保护，确保江西的母亲湖——鄱阳湖“一湖清水”。在加强现代水利建设的基础上，目前还应抓好以下工作：

（1）大力加强湿地的保护和建设

继续退田还湖，实施鄱阳湖湿地生态系工程，建立湿地自然恢复区，完善引水设施，固定或扩大湿地面积，恢复湿地植被。同时加强人工湿地建设，合理处理城镇化与湖泊湿地建设的关系，为多种野生动植物提供优质栖息、繁衍场所。加快湿地动态监测体系和基础数据平台建设，提升湿地公园建设管理水平。

（2）大力加强植树造林工作

坚持宜林则林、宜草则草的原则，积极建设环湖生态保护带，在滨湖控制开发区，建设鄱阳湖防护林，在赣江、信江、抚河、饶河、修河等五大干流沿岸，积极开展绿化带建设，重点加强水源涵养林，水土保持林及森林公园建设，形成网状、立体的鄱阳湖绿色屏障。

（3）大力加强湖区污染防治工作

污染防治是鄱阳湖生态建设的重中之重，要未雨绸缪，及时规划，防治并举，实行最严格的污染防治政策，全面提高污染防治水平。要提高污水集中处理率，严格污水排放标准，加快建设和生活垃圾处理设施和收集系统，提高固体废弃物减量化、无害化和资源化水平。特别要借鉴国外先进经验，如瑞典是全球垃圾分类利用处理最成功的国家，每 100 公斤的生活垃圾经多级利用处理后，最终的填埋量仅有 1 公斤。工业污染要从产业布局开始进行控制，提高产业准入门槛，防止产业承接中的污染转移。

（4）大力筑牢爱湖护绿的群众基础和法制基础。鄱阳湖湖域面积浩大，周边岸坡广阔，而水源发祥地五大干流延伸几百公里，没有广泛的群众基础，不能筑牢爱湖护绿的共识，保护鄱阳湖生态是一句空谈。要围绕提升百姓幸福指数，让人们喝干净水、吃放心粮，呼吸新鲜空气，广泛宣传，发动群众，使大家像爱护孩子一样，爱护鄱阳湖生态，爱护江西生态。要制定具有约束力的村规乡约，使大家自觉遵守生态保护的制度规定，并通过法律手段，划定生态保护红线范围。要完善干部生态环境考核考评制度，强化对环境污染、资源消耗、生态效益等指标考核，从源头切断“先污染，后治理”的老路，提升绿色发展水平。

鄱阳湖生态经济区目前以占全省30%的国土面积，承载了近50%的人口，创造了60%以上的经济总量。未来一段时期是全市工业化、城镇化加速推进的重要时期，节能减排任务更加艰巨，生态保护压力更加突出。因此，必须正确处理经济与生态的关系，促进绿色旅游与鄱阳湖生态建设和谐发展，从江西的实际出发，做足做大做好鄱阳湖绿色旅游这篇文章。
Promoting the Harmonious Development of Green Tourism and Ecological Construction of Poyang Lake Ecological Economic Zone

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Abstract: Poyang Lake Ecological Economic Zone construction is an important strategic initiative for Jiangxi Province to transform its economic development mode and explore the new path for coordinate development of ecology and economy. With a superior natural environment, Poyang Lake Ecological Economic Zone has abundant eco-tourism resources and rich history and cultural heritage. Based on the present situation of Jiangxi Province, this article first analyzes the scientific development and Green Rise conditions and environmentit has, then, focusing on the theme of harmonious development of green tourism and ecological construction of Poyang Lake Ecological Economic Zone, this paper studies and discusses how to give full play to the ecological advantages and implement the strategy of increasing competitiveness by developing tourism. Next, the paper elaborates the great importance of the ecological resources for the economic growth of Jiangxi Province, and puts forward ideas and suggestions on green tourism development and ecological protection.

Keywords: Poyang Lake Ecological Economic Zone, Ecological Environment, Green Tourism, Ecological Protection
赣江进入鄱阳湖的水沙及其变化

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摘要：利用赣江下游控制水文站（外洲水文站）1957—2010年径流量与悬移质泥沙输沙量监测资料，分析赣江进入鄱阳湖的水沙特征及其变化规律。结果表明：(1) 赣江入湖年径流量在近50多年来经历了先增大后减小的变化过程，自1998年起的近十几年显著减小，但总体趋势依然为增大；近十几年来（1998年之后），赣江入湖径流量明显减小，下游年径流量减小速度最快，中游次之，上游较小；赣江入湖年径流量的变化主要受年降水量变化控制，人类活动对年径流量多年变化的影响很小，在水文统计结果中尚无清晰反映。(2) 赣江入湖年输沙量在近50多年来也经历了先增大后减小的变化过程，但增大速度很小、持续时间也很短，总体上呈增大变化趋势；1991年起，由于赣江上中游一批大中型水库建成蓄水，大量拦截悬移质泥沙，赣江年输沙量快速、大幅减小。(3) 赣江入湖年输沙量与年径流量相关点群均呈双层分布，分层时间（年份）节点为1991年，与主要水库投入运行时间一致。各层相关关系较为密切，可以建立较理想的分段经验公式：年输沙量与年径流量和洪峰流量乘积的相关关系均较密切，但呈现出前、后两个年段分层现象，分层时间节点与年输沙量与年径流量关系相同。所建立的基于通用土壤流失方程的年输沙量经验公式，比未加入洪峰流量的经验公式的准确性和稳定性均明显提高，实用性更强。

关键词：赣江；径流量；悬移质泥沙；变化；鄱阳湖
外洲水文站最大年径流量 $1.49 \times 10^8 \text{m}^3$，出现在 1973 年；最小年径流量 $23.67 \times 10^8 \text{m}^3$，出现在 1963 年；多年平均年径流量 $678.65 \times 10^8 \text{m}^3$。

年径流量在 1957—2010 年 54 年中的变化，呈现出先增后减的多年变化过程（见图 1 和表 1），总体变化性质为增大变化形势（平均增大速度为每年 $1.3456 \times 10^8 \text{m}^3$），但自 1998—2010 年 13 年则为显著的减小变化态势（见图 2），平均减小速度达每年 $14.674 \times 10^8 \text{m}^3$。

![图 1 赣江年径流量多年变化过程线](#)

**表 1 赣江流域年径流量多年变化统计（$10^8 \text{m}^3$）**

| 年段       | 1970 年以前 | 1971-1980 年 | 1981-1990 年 | 1991-2000 年 | 2001-2010 年 |
|------------|------------|------------|------------|------------|------------|
| 平均年径流量 | 643.9      | 672.1      | 653.0      | 772.1      | 666.2      |

![图 2 赣江年径流量近年变化过程线](#)
外洲站年径流量的多年变化主要与流域内年降水量的多年变化密切相关，主要体现在以下几个方面：

一是该站年径流量与年降水量相关点据未出现随年段不同而分层的现象（见图4）。

$$y = 0.8272x - 420.79$$

$$R^2 = 0.7878$$

图3 外洲水文站年径流量与年降水量相关关系

二是该站降水径流双累积曲线未出现明显偏离正常方向的现象（始终保持稳定的线性关系，见图4）。

图4 赣江下游外洲水文站降水径流双累积曲线
以上两个特征，说明在赣江流域，人类活动对径流量的变化直接影响作用不大，即使有影响，也是通过对降水量的影响而间接体现出来的。

2 赣江进入鄱阳湖的泥沙及其变化

外洲水文站最大年输沙量 1860×10^4t，出现在 1961 年；最小年输沙量 169×10^4t，出现在 2009 年。最大、最小年输沙量相差 10 倍（倍比值 11.01），远远大于该站最大、最小年径流量倍比值，其形成原因在于最小年输沙量出现在受工程拦沙影响后的年份，是自然因素与人为因素共同影响的结果；多年平均年输沙量 860.88×10^4t。

年输沙量在 1957—2010 年 54 年中的变化也经历了“先增后减”变化过程，且增加期远比减小期短（见图 5），总体上呈显著减小态势，平均减小速度为每年 20.09×10^4t。年输沙量从 1991 年起发生系统性偏小现象（见图 6 和表 2），1995 年以后偏小幅度更大，造成这种现象的主要原因都是由于赣江中游首段万安水库自 1991 年建成蓄水，拦蓄大量泥沙于库区，大幅减小库下游泥沙；1995 年后赣江上中游很多中小型水库投入使用，水土保持得到迅速增强，来沙显著减少。

![图 5 赣江悬移质泥沙年输沙量多年变化过程线](image)

\[ y = -20.09x + 40708 \]
图 6 赣江下游外洲站年输沙量与年径流量双累积曲线

表 2 赣江流域年输沙量多年变化统计（10^4t）

| 年段       | 1970 年以前 | 1971-1980 年 | 1981-1990 年 | 1991-2000 年 | 2001-2010 年 |
|------------|-------------|--------------|--------------|--------------|--------------|
| 平均年输沙量 | 1197.43     | 1055.90      | 998.20       | 573.50       | 344.77       |

3 赣江进入鄱阳湖的水沙关系及其变化

外洲站年输沙量与年径流量相关点群双层分布（见图 7），1957—1990 年相关点与 1991—2010 年相关点分成上、下两层，表明自 1991 年起年输沙量显著减小。
数理统计分析表明，赣江下游外洲站年输沙量与年径流量各层相关点群的相关趋势均较显著，得到的经验公式分别为：

（1）1957—1990 年

\[ W_s = 0.1870W_q^{1.3342} \]  

（2）1991—2010 年

\[ W_s = 0.0068W_q^{1.6792} \]

式中：\( W_s \)——赣江下游外洲站年输沙量，10^4t；

\( W_q \)——赣江下游外洲站年径流量，10^8m^3。

由公式（1）和（2）可见，赣江下游外洲站水沙关系在 1991 年前、后发生了显著变化，相同年径流量对应的年输沙量大幅减小，表明在赣江流域，人类活动对水沙关系影响极大，究竟有利还是有害，厉害关系将如何演变，有待进一步观察研究。

外洲站年输沙量与年径流量和洪峰流量乘积相关点群分布规律也呈两层分布形式，1957—1990 年与 1991—2010 年相关点子呈上、下两层分布格局（见图8），且各层相关点子呈曲线型带状分布，表明分层相关关系较为密切，可以得到较理想的经验公式，分别为：

（1）1957—1990 年
\[ W_s = 17.879(W_q \cdot Q_m)^{0.6180} \]  
(3)

（2）1991—2010 年

\[ W_s = 1.6676(W_q \cdot Q_m)^{0.8205} \]  
(4)

式中：\( Q_m \) ——赣江下游外洲站洪峰流量，\( 10^4 \text{m}^3/\text{s} \)。

图 8 赣江下游外洲站年输沙量与年径流量和洪峰流量乘积相关关系

比较图 7 和图 8 可见，加入洪峰流量 \( Q_m \) 后，1957—1990 年和 1991—2010 年两段的 \( R^2 \) 值均明显加大，表明加进洪峰流量对于提高外洲水文站年输沙量模拟效果意义重大。

4 结语

本文通过对赣江下游外洲水文站断面水沙特征、水沙关系及其变化进行分析，得到一些新的成果与认识，希望有助于鄱阳湖水文、水资源与水生态环境研究。

目前赣江只在外洲水文站以上有实测水文资料，而外洲水文站到赣江进入鄱阳湖入湖口尚有 80.5km，区间集水面积达 1861km²。本文因资料原因未对外洲水文站以下区域水沙特性与水沙关系及其变化特点进行分析，待有实测水文资料之时，补充这方面分析工作，以提高对赣江进入鄱阳湖水沙、水沙关系及其变化规律的准确认识。
Abstract: The characteristics of water and sediment and the change rule of the Gan River into Poyang Lake are analysed by making use of the monitoring data of the runoff and suspended sediment discharge from 1957 to 2010 in hydrological control station of Gan river downstream (Waizhou hydrological station), the results showed that: (1) The annual runoff from Gan River into the lake has experienced the change process of increased first and then decreased in the last 50 years, Since 1998 the last ten years is significantly reduced, but the overall trend is still increasing; In the last ten years (after 1998), the annual runoff from Gan River into the lake decreases obviously, the annual runoff of Downstream decreases fastest, the middle reaches is second, upstream is slower; Changes of annual runoff in the Gan River into the lake is mainly controled by annual precipitation change, the influence of human activities on annual runoff changes in many years is very small, it have clearly reflect In the hydrology statistical results. (2) The annual sediment discharge of Gan River into the lake in the last 50 years has also experienced...
a changing process increases at first and then decreases, but the increasing speed is very small, the duration is very short also, the overall trend is increasing. Since 1991, because of a number of large and medium-sized reservoir in the middle reaches of Gan River are impounding, the suspended sediment in Gan River is intercepted of large number, the annual sediment discharge is quickly greatly reducing. (3) The related point groups of Gan River into the lake annual sediment yield and annual runoff showed a double distribution, the hierarchical time (year) nodes is in 1991, the running time is consistent with the main reservoir was put into. Each layer was rather close correlation, can set up a ideal years experience formula; Correlation of product between annual sediment yield and annual runoff and peak flow were significantly correlated, but appeared before, after two year period of stratification, the relationship between stratification time nodes and annual sediment yield and annual runoff is the same. The annual sediment yield empirical formula of established based on the universal soil loss equation is higher improved of the accuracy Stability and reliability than did not join the experience formula, and is more practical.

Key words: Gan River; runoff; Suspended sediment; Variation; Poyang lake.
加强湖泊资源保护与管理

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摘 要：湖泊作为一种重要的自然资源，具有蓄水、供水、养殖、航运和旅游等多项生态功能，在整个经济社会可持续发展中起着重要作用。针对我国湖泊保护与管理存在的问题：如面积萎缩；功能退化；水体污染日趋严重；盲目围网养殖，严重影响了防汛抗灾工作；管理体制紊乱。提出了加大湖泊管理执法力度、完善湖泊保护公众参与机制、恢复湖泊水环境质量及功能、积极探索湖泊管理模式等建议。

我国是一个多湖泊的国家，湖泊具有供水、防洪、航运、养殖、观光等多重价值，是我国社会经济发展的重要资源。近30年来，由于人类活动方式、强度和不同湖泊自然演化速度、方向等差异，导致我国湖泊出现了水污染严重、富营养化、面积萎缩以及生态功能退化等一系列的生态环境问题。湖泊出现的一系列生态环境问题，大多数是由于对湖泊资源不合理、高强度的开发与利用以及管理不善等原因造成的。发达国家尤其是美国、日本等国经过多年的研究和实践，在湖泊管理方面取得了相当的进展，积累了许多有益的经验。

在借鉴发达国家湖泊管理经验的基础上，笔者期望通过对我国湖泊管理现状的分析，探究湖泊管理中存在的主要问题，探索符合我国国情的湖泊管理新思路，构建我国湖泊管理新体系，以实现我国湖泊资源的高效、可持续发展和利用。

1 我国湖泊管理的现状

（一）行政分级管理、部门分工管理与湖泊流域管理相结合的湖泊管理体制

我国现行的湖泊管理体制可以概括为行政分级管理、部门分工管理与湖泊流域管理相结合的特征，根据《中华人民共和国水法》，我国现行水资源管理体制实行流域管理与行政区域管理相结合的管理体制。因此，对湖泊水资源的管理基本遵循该规定，国务院水行政主管部门负责全国水资源的统一管理和监督工作，部分重点湖泊设立流域管理机构，如太湖流域管理局；在所管辖的范围内行使法律法规所规定的以及国务院水行政主管部门所授予的水资源管理和监督职责，县级以上地方人民政府水行政主管部门按照规定的规定权限，负责本行政区域内水资源的统一管理和监督工作。

（二）湖泊管理法律法规体系已初步建成，但仍需进一步完善

当前，我国湖泊管理法律法规体系已初步建成，现行国家层面的法律法规体系中多处体现了对湖泊资源的保护以及合理开发利用。《宪法》主要从国家职责和公民义务方面，对自然资源的保护做了原则性的规定，湖泊作为我国重要的自然资源之一被涵盖其中。与湖
泊水资源和水环境保护有关的法律法规主要包括：《中华人民共和国环境保护法》、《中华人民共和国水法》、《中华人民共和国水污染防治法》、《中华人民共和国水污染防治法实施细则》、《中华人民共和国水土保持法》等。在《中华人民共和国水法》中规定了包括湖泊水资源在内的我国的水资源管理体制，水资源规划，水资源开发利用，水资源水域和水利工程的保护等方面的内容。其他相关的一些法律法规，如《中华人民共和国渔业法》、《中华人民共和国渔业法实施细则》等也明确规定了包括湖泊渔业资源在内的渔业资源的合理开发利用，保护，监督管理等内容。但是，目前我国尚没有一部国家层面的专门针对湖泊的法规。

2 我国湖泊管理存在的主要问题

（一）我国湖泊的管理体制不健全

我国现行的湖泊管理体制呈现条块分割、多头管湖的局面。在横向管理上，湖泊水资源归属于交通、水利、渔业、环保、市政和林业等十多个部门分工管理，各部门之间的管理职责有明显的交叉与重合，部门之间的责、权、利关系不清晰，各自为政，缺乏沟通和协调的问题比较突出，形成“多头管湖”的局面。在纵向管理上，形成了中央统一管理和地方辖区管理相结合的特征，地方管理结构受中央直属部委统一管理，而同时又隶属于地方政府管理，缺乏独立的管理权限，导致地方管理机构往往难以执行中央管理部门对其的要求，呈现条块分割管理状况。此外，我国大部分湖泊并未从流域的角度进行综合管理，只有部分重点湖泊设有流域管理机构，作为国家有关部委的派出机构，其与地方行政机构之间的协调性较差，对湖泊流域进行综合管理的作用有限。现行这种条块分割、多头管湖的湖泊管理体制使得我国湖泊管理职责不清、部门协调困难，导致了我国湖泊管理一些问题长期得不到解决。

如在行政执法管理体制方面，渔业与海事、航道执法管理体制较为系统，水政监察功能有待发挥。渔业部门从省级到县级都有行政主管部门，都设有渔政执法机构，且上下级之间分工明确，管理层次清晰。在水利方面，虽然也建立水政监察体系，但水利部门的湖泊执法管理能力有待加强。在产权管理体制方面，存在经营性产权部门化、公益性产权模糊化，产权配置行政化、产权体系零碎化等现象。例如，养殖水面、湖内捕捞等权益的配置由渔业部门控制，工业用水、饮用水取水的权益由水利部门掌握，这些具备效益能力的产权由不同部门控制，并采用行政手段来配置，缺乏市场化手段。

（二）湖泊法律法规体系与发达国家存在一定的差距，体系的完整性和系统性有待加强

湖泊管理的法律体系是一体化的，相互联系的有机整体，应形成由基本法律和与之相配套的一系列法规、实施细则组成的体系。一些发达国家专门有针对湖泊保护和管理的基本法律，如日本很早就在全国颁布实施了“湖泊法”。但迄今为止，我国尚没有一部专门针对湖泊保护和管理的国家基本法律，这导致我国湖泊管理内部法律法规之间缺乏协调，各为体系，尚未组成一个有机的体系。国家层面的由各部门制定的如“水污染防治法”、“渔业法”等，以及地方政府各自制定的湖泊保护法律法规之间，皆因缺乏一部具有协调性的基本湖泊法而导致彼此之间缺乏协调衔接，甚至存在相互矛盾和歧义之处。此外，虽然一些地方政府制了地方性湖泊保护条例，但实施力度不够，且很多地方政府至今尚未出台相应的湖泊保护地方性法规。由此可见，我国湖泊管理法律法规体系存在结构性缺陷，湖泊法律法规与发达国家存在一定的差距，体系的完整性和系统性有待加强。

（三）湖泊管理中的公众参与不足

公众环境意识及公众参与是发达国家湖泊管理成功的基础和宝贵经验，如日本治理琵琶湖
湖，开展了用肥皂代替合成洗涤剂的全民运动，削减入湖污染负荷；加拿大在圣劳伦斯河的治理过程中，积极鼓励社区群众参与治理流域水污染，瑞典水环境治理的成功动力是公众对高质量水环境的追求。由于公众参与机制缺乏以及公众环境参与意识薄弱，导致我国公众环保意识和公众参与度与发达国家相比存在相当大的差距。目前，中国公众参与湖泊治理的各种形式均存在一定的局限。具体而言，多方参与协商模式面临的主要问题是由于相关利益方的代言组织还没有发育完全，很多时候是由相关政府部门代行，并不能完全代表相关利益；公众听证方式的主要问题是参与者选择易受政府方操控，由于信息不对称，听证会代表难以对听政方案提出实质性的质询意见，听证记录对政府决策缺乏明确的约束作用；专家论证方式的主要问题是参与者对相关利益代表负有道德风险；征询意见的方式面临的主要问题是参与者意见分散，且易受舆论误导，这种方式对政府决策发挥的作用有限。因此，完善我国公众参与机制，提高湖泊管理中公众参与的任务仍然相当艰巨。

3 我国湖泊保护和管理的新探索

（一）建立完善的湖泊保护法律体系

结合各地实际情况，完善地方湖泊保护方面的法律法规，进一步推进地方湖泊保护条例的实施，并推进相关配套法律法规的制定、科学论证。建立和健全各省湖泊管理和保护的法制体系，做到湖泊管理有法可依、法尽其用。可积极推进“一湖一法”，各级政府可出台保护当地湖泊的地方性法规，为依法保护湖泊提供法律保障。

（二）明确湖泊的功能定位，建立湖泊管理的长效机制

科学认识湖泊在区域生态、社会经济发展中的作用，明确它们的功能定位，严格按照功能定位，优先发挥湖泊的主要功能。同时兼顾其它功能，实施保护与合理利用相协调。盲目围网养殖已经成为湖泊生态环境保护面临的主要问题之一，如何合理科学地安置湖区渔民是湖区可持续管理的关键问题，也是社会和谐的大事。一些湖泊，如洪湖，虽然国家重点支持完成了养殖围网的拆除，一次性给予渔民经济补偿，但是这些渔民生产如何转型、如何发展替代产业，以及如何得到有效地规划和落实，使得湖泊问题出现反弹。建议政府部门出台相关政策，管理部门加大执法力度和具体管理措施，建立湖泊管理的长效机制，明确责任追究机制，完善湖泊保护体系，制定湖泊保护和利用的科学规划，把重要湖泊纳入保护区和湿地公园体系建设中来，提高湖泊管理和保护的现代化水平，健全湖泊保护机构，设立湖泊综合保护监管机构，将人员职责落到实处，确保湖泊保护监管手段和执法能力，彻底杜绝填湖、占湖、污染湖泊、破坏湖泊生态环境的违法事件发生。

（三）完善湖泊的生态治理和修复

借鉴国内外水环境治理的有益经验，把控制外源和内源结合起来，对入湖河流实行“一河一策”的严格控源截污措施，严格控制农业污染、工业污染物及城市污水的排放。同时运用生物工程措施，恢复与重建湖泊水生植被，把严格控制污染物排放与发挥湖泊水体的自净能力相结合，通过污水处理与清水补源机制的修复以及流域管理等形成绿色流域，以重要江河流域主要水系河道为基本框架，研究制定切实可行的优化水资源配置体系，充分发挥湖泊的水资源配置和调蓄作用，形成布局合理、连通有序、生态健康、引排得当、丰枯补调、多源互补的江河湖水系连通格局。

(四) 改进管理手段，增强事前预防性管理能力
社会经济中各项涉湖活动对湖泊的影响，有的在短时间内可以体现，而有的则需要一段相对较长的时间才能体现。一般说来，湖泊内资源、生态环境遭受破坏之后，可恢复的程度难以预料并且恢复成本很高。因此，采取预防性措施，防止资源、生态环境的破坏是管理的理想手段，事前预防性的管理要比事后矫正性管理更有价值和更为重要。要逐步改变以往的以事件管理和行为管理为主的管理思维，增强预见性，加强事前预防性管理。

（五）建立湖泊保护的公众参与机制，建设节水防污型社会

改变“公众提出意见—管理部门处理意见”的消极被动方式，将公众力量纳入到湖泊保护的规划编制、实施以及监督等工作中。在管理体制上可以考虑湖泊产权管理的需要，明确湖泊的产权界定、维护、保障与限制，鼓励非政府组织、私人团体和公民开展湖泊保护行动，规范各利益相关者的行为。进一步增强广大干部群众的湖泊资源保护意识，提高全民节水意识和生产生活用水效率，切实保护好湿地资源。

（六）强化落实湖泊保护规划，探索建立涉湖专业规划的审核、审查制度

湖泊保护规划是有关湖泊保护工作的总体安排。部分省水利厅和有关部门所进行的湖泊综合性规划编制工作还有待修改完善，把它作为湖泊保护、开发、利用和管理的依据。制订综合性规划，应根据湖泊各个功能的重要性程度确定各个湖泊的主导功能，并明确各个湖泊的重要保护内容、划定湖泊保护的范围并分别采取不同的保护管理措施。应突出规划的强制性作用，建立湖泊保护规划实施评价制度，对涉湖规划进行审核或者审查，强化各个参与规划实施的部门的责任和任务。

参考文献

[1] 陈梦熊,马凤山.中国地下水资源与环境.北京:地震出版社, 2002.

[2] 崔亚莉,张戈,邵景力.黄河流域地下水系统划分及其特征.资源科学, 2004, 26(2): 2-8.

[3] 王珍岩,孟广兰,王少青.渤海莱州湾南岸第四纪地下卤水演化的地球化学模拟.海洋地质与第四纪地质, 2003, 23(1): 49-52.

[4] 余秋生,张发旺,韩占涛等.地球化学模拟在南北古脊梁岩溶裂隙水系统划分中的应用.地球学报, 2005, 26(4): 375-380.
Strengthening the Protection and Management of Lake Resources

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Abstract: The lake plays an important role in the sustainable development of the whole economic society as a kind of important natural resources, with functions of storage, water supply, aquaculture, shipping and tourism. In view of the existing problems of lake protection and management seriously affected the work of flood control and disaster management system disorder such as the area of atrophy; function degradation; serious water pollution; blind fence breeding. Put forward to some suggestions such as law enforcement, lake participation mechanism, the restoration of water environment quality and the lake management mode.
江西鄱阳湖南矶湿地生态旅游发展模式探讨

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摘要：生态旅游已成为当今世界旅游发展的主要趋势，也成为湿地生态系统保护与湿地资源开发的有效方式。本文选取江西鄱阳湖南矶湿地国家级自然保护区为研究区，通过分析其资源环境特点以及旅游开发现状，从功能分区、生态旅游产品开发、社区参与旅游发展、湿地资源环境保护和旅游服务设施建设等五个方面探讨南矶湿地生态旅游发展模式，以期为湿地自然保护区的生态旅游开发提供重要的参考价值。

关键词：湿地生态旅游；发展模式；鄱阳湖南矶湿地；自然保护区；社区参与

生态旅游作为旅游可持续发展理念的一种实践模式，是以具有生态美的景观为旅游对象，通过旅游生态环境的营造、旅游资源的保护性开发、旅游产品的绿色经营管理、旅游者的生态消费，旅游利益相关者的生态教育，以及与旅游社区的共赢发展等方式，而开展的一种有助于旅游地和旅游业可持续发展的旅游活动[1]。目前，生态旅游已成为旅游业的一个热点和旅游者的一种时尚。湿地生态旅游是生态旅游的重要组成部分，是以具有生态美的湿地景观为旅游对象，通过湿地旅游资源的保护性开发而开展的一种有助于湿地保护和旅游业可持续发展的旅游活动[2,3]。目前，我国列入国际重要湿地名录的湿地已有30多处，建成各类湿地自然保护区350多处，大部分均已经开展了以观光、观鸟、狩猎和科学考察为主要形式的旅游活动。然而，在生态旅游的概念和原则目前尚处在探讨阶段的背景下，湿地作为处于水域和陆地过渡形态的自然体，其突出的生态脆弱性决定湿地生态旅游开发具有更大的潜在生态风险。事实上在自然湿地开发和建设上一直都伴有争议。

江西鄱阳湖南矶湿地国家级自然保护区位于鄱阳湖主湖区南部（28°52’21”~29°06’46”N，116°10’24”~116°23’50”E），为赣江北支、中支和南支汇入鄱阳湖开放水域冲积形成的三角洲前缘，总面积为333km²，其主要保护对象是赣江入湖口湿地生态系统以及赖以生存的野生动植物资源[4]。然而，近些年来，保护区周边围垦湿地（特别是“堑秋湖”）、火烧草洲等破坏湿地资源的行为屡禁不止，对南矶湿地保护区构成了严重的威胁。因此，如何在有效地保护南矶湿地生态系统的前提下，合理地开发湿地生态旅游资源，不仅具有重要的理论意义，而且更具有重大的实践意义。

1 旅游开发现状

1.1 旅游发展现状分析

长期以来，由于对南矶湿地资源的多种功能认识不足，只注重农业资源的开发利用，而忽视了湿地资源的综合开发，特别是旅游资源的开发利用，造成了资源的最大浪费。虽然建
立南矶自然保护区后,于2005年10月至2006年6月在实施IUCN-荷兰委员会小额湿地赠款项目中,由保护区组织开展了基于当地社区的生态旅游相关活动,但因经验、技术、资金和时间方面的问题,这些活动随着项目的结束而中止。目前出现的旅游活动,主要是以观鸟为主,但多是自发零星的。总体而言,南矶湿地旅游资源开发潜力大,但旅游业尚未得到真正意义上的开发,生态旅游业更是处在萌芽探索阶段。

1.2 旅游开发中存在的问题

首先,南矶湿地与周边县、乡以河为界,在丰水期形成的宽阔水域成为一道与外界交流的天然屏障,导致旅游活动开展的可达性较差。其次,南矶湿地为血吸虫病流行地区,在一定程度上阻碍了旅游业的发展。再者,目前出现的旅游活动,以大众观鸟为主,旅游产品单一;观鸟旅游线路单一,缺乏趣味性和参与性;观鸟活动季节性强,旅游适游期短。最后,当地社区居民由于缺乏旅游的常识与相关技能,加上基础设施落后,农家乐、渔家乐等发展缓慢,服务业产值几乎为零,社区居民的旅游获益有限。

2 发展湿地生态旅游的SWOT分析

2.1 优势(Strengths)分析

2.1.1 生态旅游资源丰富

南矶湿地作为典型的湖口湿地生态系统,深受赣江和鄱阳湖水文节律影响,水陆更替强烈,形成时空动态特征明显的湿地景观。春夏丰水期(4-9月),整个三角洲地区除总面积不足4km²的南山岛和矶山岛外,其它湖泊和草洲均被洪水淹没,成为鄱阳湖浩瀚水域的一部分,处于典型的湖相水文状态;秋冬枯水期,湖水消退归入河道和一些碟形洼地,不同高程的洲滩相继出露,整个三角洲地区呈现河、湖、洲交错的自然湿地景观。另外矶山岛上分布有鄱阳湖罕见的丹霞地貌和袖珍森林生态系统。复杂多样的湿地生态环境,不但有很高的观赏价值,而且有很高的科研价值。

南矶湿地完整的河口湿地生态系统,为湿地物种提供了异质多样的栖息地,孕育了丰富的生物多样性。通过综合科学考察(2003-2005年)记录到维管束植物443种(其中水生植物156种)、浮游动物111种、底栖动物62种、水生昆虫168种、鱼类58种、两栖动物11种、爬行动物23种和哺乳动物22种。尤其是鸟类,南矶湿地是重要的水鸟越冬地和中继站,每年越冬或过境的水鸟有80余种,数十万羽。除列入国家Ⅰ、Ⅱ级保护的28种鸟类,还有16种水鸟种群数量超过到国际重要湿地的标准。

南矶山还有深厚的文化底蕴,不仅有浓郁的南矶渔家文化和令人神往的神话传说,还有独特的历史文化资源。南矶乡在元朝末年百为朱元璋与陈友谅水师大战鄱阳湖时的屯兵之地,留下了很多战争遗迹,例如,藏兵洞、忠臣庙、刘伯温钓鱼台、穿盔甲、马子山等,这些遗迹能整合开发为一条非常好的明史遗迹探寻游线路。同时,南矶乡自明代以后就有居民因捕鱼、贸易或逃荒而陆续迁至南矶山定居,每个家族都有自己的一部安家立业和发展壮大的奋斗史,塑造了这里丰厚的文化底蕴和独特的民风民俗。

2.1.2 区位优势突出

南矶湿地距离江西省会城市南昌市区仅60公里,可以很好地接受南昌的辐射。南昌拥有国际机场、城际铁路、黄金水道以及多条客运铁路、高速公路构成的发达立体交通网,可
2010年南昌全市总人口近500万，国内外旅游人次在1500万以上，为南矶山旅游提供了巨大的客源优势。

2.2 劣势（Weaknesses）分析

2.2.1 湿地生态系统比较脆弱

南矶湿地由于丰水期形成的宽阔水域，可达性较差，这在一定程度上也缓解了大规模人为开发活动对自然湿地的侵占和破坏。但由于深受赣江和鄱阳湖水文节律影响，南矶湿地的生态脆弱性突出，主要表现在水源供给脆弱性和抗人类干扰的脆弱性。前者主要表现为近几十年来鄱阳湖出现的异常水位变化，多年来连续出现历史罕见低水位，且枯水期提前、低水位持续时间延长，导致湿地生态系统向陆地型转变，候鸟有效栖息地面积极大减少。后者主要表现为小孔径网、电鱼、定置网等非法捕捞，严重威胁渔业资源的可持续性。

2.2.2 旅游业整体水平不高

目前南矶湿地旅游资源开发基本处于初级阶段。旅游资源产品化程度低，已开发的观鸟等旅游产品表现形式单一，湿地文化和科普内涵挖掘不够，旅游产品整体开发水平不高；交通等公共基础设施落后，缺乏基本的旅游服务接待设施，南矶湿地所在的南矶乡只有一家规模较大的酒店，但档次较低，加上从业人员旅游常识与相关技能缺乏，旅游服务整体水平不高；旅游营销不够，湿地旅游资源的市场知名度低。

2.3 机遇（Opportunities）分析

2.3.1 生态旅游发展迅猛

随着世界经济的发展和人们生活水平的提高，旅游已经成为人们休闲度假的主要选择之一。同时，我国旅游业快速发展的总趋势将给各地旅游业带来更大的发展机遇。生态旅游作为旅游可持续发展的一种理想模式以前所未有的速度迅速发展壮大。有关资料显示，生态旅游已成为我国旅游业中增长最快的一部分，年增长率达到了30%以上。

2.3.2 鄱阳湖生态经济区建设

2009年12月，国务院正式批复《鄱阳湖生态经济区规划》，这是我国第一个冠名“生态”的经济建设示范区。与此同时，国家旅游局将鄱阳湖生态旅游区建设纳入国家旅游发展战略，并组织编制《鄱阳湖生态旅游区规划》。在这些国家战略的引领下，江西省明确提出“把以生态旅游为主的旅游业培育成新的支柱产业”，省旅游业发展总体规划确定了生态旅游的主导地位，并将鄱阳湖湿地（涵盖南矶湿地）生态旅游列为首批生态旅游试验区。这为南矶湿地生态旅游的发展提供了良机。

2.4 威胁（Threats）分析

2.4.1 区域市场竞争加剧

目前环鄱阳湖知名度较高的旅游景区有庐山、石钟山等，这些景区的开发时间比较早，旅游市场已经很成熟且具有较大规模，对游客的吸引力也相对较大。即使新近开发的鄱阳县鄱阳湖湿地公园，以及吴城镇的鄱阳湖国家级自然保护区，其知名度也远比南矶湿地自然保护区高。随着旅游业的进一步发展，客源竞争将更为激烈。
2.4.2 旅游发展与环境保护的矛盾

近几年，我国开发和建设湿地旅游的项目逐渐增多，由于我国对湿地及湿地旅游的认识和研究仍处初级阶段，一些观念和认识并不统一，对湿地保护与开发程度看法不同，再加上某些自然湿地的权属关系并不明晰，缺乏相应的法律保护，旅游开发往往造成自然生态系统退化及旅游特色资源原貌的破坏。这类问题同样存在于南矶湿地旅游开发中。虽然建立了南矶湿地自然保护区，但保护区内的许多湿地权属不清。目前南矶湿地保护区内的26个蝶形湖泊均承包给了个人进行“堑秋湖”渔业活动，从而经常有人鸟争地、人鸟争食等干扰越冬候鸟栖息觅食、破坏湿地生态的现象存在。当前南矶湿地保护区与当地社区之间的主要矛盾也主要体现在对枯水期间季节性湖泊的保护与利用之上。

南矶湿地发展生态旅游的SWOT分析结果见表1。

表1 南矶湿地发展生态旅游的SWOT分析

| 优势（Strengths） | 劣势（Weaknesses） |
|----------------|-------------------|
| 生态旅游资源丰富 | 湿地生态系统较脆弱 |
| 旅游区位优势突出 | 旅游业整体水平不高 |
| 机遇（Opportunities） | 挑战（Threats） |
| 生态旅游发展迅猛 | 区域市场竞争加剧 |
| 鄱阳湖生态经济区建设 | 旅游发展与环境保护的矛盾 |

3 南矶湿地生态旅游发展模式

3.1 发展理念

南矶湿地生态旅游需以和谐共生、持续发展为其理念。基本要求是：在维持湿地生态系统的完整性和当地社区文化的延续性的前提下，以生态旅游市场为导向，通过旅游产品的绿色经营管理，满足旅游者理解湿地和当地社区文化价值基础上的生态美的体验，实现旅游业的可持续发展能力、保护区的保护管理能力和社区综合发展能力的提高。

3.2 发展原则

南矶湿地生态旅游发展需坚持以下原则：

（1）生态优先、适度开发原则。在正确处理好南矶湿地的自然景观、文物古迹和民俗文化的保护、研究、开发利用的关系前提下，按照“动态可持续”目标模式的生态旅游发展理念[5]，实施积极的保护性开发战略。一方面严格按照功能分区，对具备现实开发和保护条件的旅游资源，在环境可承受范围内有控制地加以旅游产品开发；对目前还不具备开发和保护条件的潜在旅游资源，除科研、科考等非消费性活动外，要严格加以保护。另一方面，应积极进行生态建设，如对因“堑秋湖”这种传统渔业活动导致的退化湿地进行生态修复与重建。生态优先原则应体现和贯穿在生态旅游建设与管理全过程中。

（2）政府引导扶持原则。南矶湿地旅游发展目前仍处于探索阶段，政府要发挥旅游发展的开拓者作用，组织制定旅游发展相关规划和相应的宏观政策。在南矶湿地旅游逐步发展至成熟期，政府要发挥旅游发展的监督管理者和协调者作用，在政府宏观调控的基础上，推动旅游的市场化运作，一方面制定完善相关的法律法规，实行依法治旅，推动旅游绿色经营、生态教育培训、旅游科研等工作，另一方面要协调旅游发展的各方面关系。

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（3）生态教育的原则。生态旅游的成效在很大程度上取决于旅游从业人员、游客和社区居民的生态文明程度。提高旅游业管理者、企业、游客与社区居民的生态素质，有助于生态旅游的顺利推进。生态教育原则应体现和贯穿在生态旅游建设与管理全过程中。

（4）综合效益最优化原则。南矶湿地旅游发展应以实现旅游业和旅游地（南矶湿地和当地社区）的可持续发展为价值取向，以环境效益为前提、经济效益为保障、社会效益为依据，近期获得三大效益协调发展而呈现的综合效益最大，远期获得建立在经济可持续、社会可持续、环境可持续基础上的三大综合效益的可持续性最佳效益。

3.3 湿地生态旅游的发展模式

围绕“保护与利用”两大主题，分别从功能分区、生态旅游产品开发、社区参与旅游发展、湿地资源环境保护和旅游服务设施建设五大模块来构建南矶湿地生态旅游发展模式。

3.3.1 功能分区

功能分区是根据旅游地的自然地理特征、保护对象级别、资源的重要性等划分出不同的保护与管理区域。科学的功能分区可以使旅游资源得到保护性的开发管理。根据 Richard Forest 提倡的同心圆模式（核心保护区、游憩缓冲区和密集游憩区）和 Clare A Gunn 提出的 5 圈层（重点资源保护区、低利用荒野区、分散游憩区、密集游憩区和服务社区）国家公园旅游分区模式，结合本区生态环境敏感性和生态系统服务功能重要性程度等，将南矶湿地划分为核心区、缓冲区、实验区和发展控制区4部分。

核心区：为南矶湿地保护区主要保护对象集中分布的区域，范围以东湖、神塘湖、下段湖、泥湖、下长湖、珠湖、白沙湖、山南湖等为中心。该区功能是保存典型湖泊湿地生态系统，以赣江入湖水系为代表的典型河口三角洲和以白鹤等为代表的珍稀濒危或特有动植物生境。该区域严禁人为活动直接干扰，可开展科研和环境监测活动。

缓冲区：为环绕核心区的周围地区，是核心区与实验区之间的过渡地带，保持着与核心区相同的生态特征与生物群落。其主要功能是保护核心区，以缓冲外来干扰对核心区的影响。范围包括饭湖、上段湖、上长湖、大车荒湖、红星湖、北深湖、风尾湖、石湖等湖泊。可开展以保护为目的的科研、科普活动，禁止有生产性经营活动，在严格控制人为活动干扰下，局部地区可适当建设观鸟亭等景观。

实验区：为人类活动比较频繁的地区，该区土地利用程度较高，自然生态系统受损程度较大。主要以湖塘湖、南深湖、常湖、战备湖、曾备湖、三泥湾等季节性湖泊为主，分布在南矶乡对外交通干线周边。可开展科普、草洲竞技、太子河水上观光等活动。

发展控制区：主要依托南山岛和矶山岛，布置主要的旅游基础设施，如游客服务中心、湿地博物馆、度假休闲会务中心、商业街、停车场、生态渔村等。
### 表 2 南矶湿地自然保护区功能分区及其旅游开发建设项目

| 功能分区 | 旅游开发分区 | 旅游开发项目 | 限制的旅游开发项目 |
|-----------|---------------|---------------|-----------------------|
| 核心区    | 绝对保护区   | 科考、科研、环境监测、视觉观光（观鸟） | 严禁湖面机动船娱乐、禁止修建公路 |
| 缓冲区    | 控制保护区   | 科考、科研、科普、环境监测、观鸟 | 禁止修建公路 |
| 实验区    | 旅游娱乐区   | 科普、观鸟、草滩娱乐，以及活动厕所、垃圾收集点等 | 禁止修建停车场、垃圾运出区外 |
| 发展控制区 | 旅游服务接待区 | 游客服务中心、停车场、度假休闲会务中心、商业街、农家乐、渔家乐等 | 控制建筑体量，人工构筑物风格统一并与湖泊湿地环境协调等 |

#### 3.3.2 生态旅游产品设计

以南矶山独特的湿地生态景观和湿地文化为特色，充分发挥湿地资源内涵，突出个性，构建湿地生态旅游产品谱系，全力打造“候鸟天堂、渔岛风情”这一特色品牌，把南矶山建成形象鲜明、特色突出、设施完善的生态旅游目的地。

（1）湿地科考候鸟观赏游

可开展湿地生态系统考察、湿地生物多样性考察、湿地动植物考察、候鸟习性考察等。特别是观鸟活动，除现有观鸟台外，还应根据鸟类分布情况，建设若干个隐蔽观赏点，供旅游者或专业人士使用，并可定期举办爱鸟节，介绍南矶湿地鸟类多样性。

（2）湿地探索科普教育游

可通过建立南矶湿地博物馆开展湿地环保教育大课堂、湿地绘画比赛、湿地摄影展等活动，或组织参与渔业部门的水生生物增殖放流活动。

（3）水域观光湖滨休闲游

在春夏丰水期通过游船开展水上观光。并通过将湖水提升上岸上滩上丘，利用较浅湖面区域，可打造各种水上小屋、垂钓平台，开展亲水山林、曲水流觞等休闲项目；通过湖岔港湾及湿地水体的灵活分割，可打造各种形态的休闲水庄、渔庄等。利用秋冬冬湖水退后形成的广袤湖滩草洲，开展草滩野营野炊、健身竞技等旅游活动。

（4）渔事农耕生态体验游

结合当地社区的渔事农耕传统，开展田园风光旅游、农家渔家乐体验游等，充分挖掘当地的资源潜力，增加对游客的吸引力，同时让当地居民从旅游业中直接受益。

（5）历史遗迹探寻文化游

通过深度挖掘南矶山独特的自然和历史文化资源，开展历史文化游（如朱元璋与陈友谅水师大战）、湿地自然历史游（如南山岛和矶山岛历史变迁）、民俗文化游（如南矶乡大家族史）、饮食文化游（独特的湖岛渔村饮食）、商品文化游（如湿地动植物标本）等，把人文景观与自然景观结合起来，丰富文化内涵与游览空间，形成叠加吸引力和整体优势，提升旅游产品的整体品质，可大大增强湿地旅游的吸引力和感染力。
3.3.3 社区参与旅游发展

湿地生态保护与开发会牺牲当地社区的某些利益。因此当地社区作为湿地生态旅游环境的一个重要构成要素，他们的参与和支持是生态旅游发展的基本保障[7, 8]。为了让社区参与到生态旅游发展过程中，参与的内容主要包括六个方面：①参与旅游发展决策；②参与旅游规划、开发、经营与管理；③参与旅游收益的分配；④参与旅游相关的教育培训；⑤参与旅游资源、环境和文化的保护；⑥参与保护区共同改善基础设施。当地社区通过主动参与生态旅游发展，维护本社区的合法权益，同时也要努力提高自身的能力，如提高有效利用资源的能力，合理改造“堑秋湖”等传统旅游资源的开发方式；发展多样化的生态产业，增强社区的综合发展能力；改变传统不科学的生活生产方式，以减少对当地资源环境的压力和破坏等。国内外许多生态旅游开发成功的案例也表明，积极发动当地居民参与到生态旅游发展，不仅能增强旅游产品特有的地方文化特色，提高旅游区的生态吸引力，同时也能让当地居民从旅游产业中直接受益，使当地居民更自觉地保护旅游资源和环境。

3.3.4 湿地资源环境保护

生态旅游的发展要维系旅游地自然的完整性和文化的延续性，体现环境关怀的思想。在南矶湿地生态旅游发展过程中，一是要在旅游发展规划中科学编制湿地生态保护规划，内容应包括生物多样性规划、水生态保护规划、科研监测及科普规划、文化多样性规划和环境保护规划（噪声控制、旅游生活垃圾排放控制及环境卫生等）等。二是要严格执行环境影响评价制度，环评的重点主要是生态旅游对湿地资源和环境的影响分析、旅游环境容量的评估分析、生态保护和恢复的技术方案及管理措施评价、环境保护治理工程的评价、生态影响的效益分析等。三是要建立湿地地理信息系统，开展资源环境动态监测，在生态旅游地主要景区（点）建立定位与半定位观测站、点对生态旅游环境进行跟踪观察研究，随时掌握湿地生态环境动态变化。四是要建立生态补偿制度，从旅游经营单位收取一定的补偿费，用于相应的资源环境养护和恢复。五是要加强生态教育，通过对旅游者、旅游从业者、旅游管理者和当地居民进行生态教育，以及对旅游相关者（如旅游研究者、旅游协会组织等）的生态引导支持，营造一种和谐共生、持续发展的旅游发展环境。

3.3.5 旅游服务设施建设

首先，提升景区的公共交通线路布局，根据景区地形地貌特点，加快道路改造；在建设过程中还要进行沿路景观的保护与修复工作，可以采取植被固坡等形式进行补救，在河流流经的地区以及野生动物经过的主要道路上，采取立体交叉的方式设置道路，保护生态走廊。其次，应提升景区内的旅游接待服务，鼓励周边的家庭旅馆和农家院提档升级等，同时旅游服务设施的建设要与湿地环境及生态系统相协调，以及配套建设污水、废弃物等处理设施。再者，建立湿地生态旅游科学解说系统，在景区建立湿地博物馆、观鸟亭台、亲水平台、科普栈道等设施，科学设置多种个性化的解说标牌、环境保护指示牌等。

4 小结

生态旅游是回归大自然的旅游方式，由于其尊重自然与文化的异质性，强调保护生态环境与将富当地社区居民，倡导人们认识自然、享受自然、保护自然、参与自然，被认为是旅游业可持续发展的最佳模式之一。南矶保护区具有独特的湖泊湿地景观资源，具有发展生态旅游的巨大潜力。因此，应以可持续发展战略为指导，根据湿地景观资源的特点，科学合理地进行功能分区和旅游产品设计，树立品牌，使旅游业成为南矶保护区湿地保护和管理的经
The Discussion on Development Model of Wetland Ecotourism for Lake Poyang-Nanji in Jiangxi

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Abstract: Nowadays ecotourism has become the main tendency of tourism development, and it also becomes the effective way to protect wetland ecosystem and explore wetland resources. The paper took the national natural reserve of Lake Poyang-Nanji wetland as a case study. Based on the analyses of characteristics of tourism resources and environment for Lake Poyang-Nanji wetland and the tourism exploitation actuality, the development model of wetland ecotourism was discussed from functional division, ecotourism product development, community participation in tourism development, the protection of wetland resources and environment, and the construction of tourism service facilities, so to provide the reference and instruction for the ecotourism development in wetland natural reserves.

Key words: wetland ecotourism; development model; Lake Poyang-Nanji wetland; natural reserve; community involvement
江西省规模化猪场废水处理现状及污染控制措施

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摘 要: 通过对江西省规模化养猪场水污染现状进行统计分析, 指出猪场废水中过高浓度的有机物、重金属、抗生素等污染物对大气、水体和土壤等环境带来的潜在危害, 并就江西省规模化养猪场废水治理现状进行归纳分析, 提出了针对小型、中型、大型养猪场废水对应的可行性技术推荐。

关键词: 江西;规模化养猪场;废水处理;技术推荐

随着“昌九一体化”的新型城镇化发展进程的加快, 工业废水、生活污水以及农业面源污染等都将对江西省整体生态环境特别是鄱阳湖流域水体质量造成严重威胁, 面临日益严峻的水污染和湿地退化现象。因此, 维护鄱阳湖“一湖清水”, 保障长江中下游水生态、水环境的安全问题将成为核心关键问题, 其中规模化养殖畜禽粪便污水治理便是影响的主要原因之一[1,2], 而规模化养猪场作为江西省规模化养殖业中的重要组成部分, 对它产生的粪污进行有效治理显得意义重大。

1 江西省规模化养猪场现状

江西是一个农业大省，畜禽养殖业快速发展的同时，饲料方式也在发生巨大的变革，规模化养殖正逐渐替代传统的养殖模式，成为畜禽养殖生产的主导。据统计，2013 年，江西省出栏生猪 3213 万头，家禽 4.41 亿羽，分别增长 2.6%和 1.9%，全省肉类总产量达 343 万 t，禽蛋 57.5 万 t，鲜奶 13.3 万 t，畜牧业产值达 368 亿元，占全省农林牧渔总产值的 30.0%。按存栏数≥500 头以上的规模化养猪标准统计，目前江西省共有规模化养猪场 10638 个，全省各个地区均有分布，其中以宜春市和南昌市分布最多，宜春市有 2822 个，南昌市有 1570 个，两者约占总数的 41.3%；吉安、上饶、抚州、赣州、九江市规模化养猪场数量接近，各占总量的 9%左右。这些规模化猪场中已完成粪污治理改造的猪场有 2851 家，仅占规模化养猪场的 26.8%；正在建设的规模化养猪场有 265 家，仅占规模化养猪场的 2.48%。因此，江西畜牧养猪业造成的环境污染已经成为继工业污染后的又一重要污染源，对江西生态环境质量有着极大影响。

2 江西省规模化养猪场废水治理面临的挑战

规模化畜禽养殖业的快速发展必然会引起其粪便污染问题，饲养规模越大，单位面积土地的载畜量越高，造成当地环境所承受的污染负荷越大，其已成为全省生态环境保护面临的严峻挑战。根据江西省环境状况公报可知，2013 年江西省规模化畜禽养殖场排污达标率为 50.0%左右，而 COD 和氨氮排放浓度也分别为 14~1635 mg/L 和 0.561~359 mg/L。同时，通过分析江西省污染源可知，畜禽养殖业是水体 COD 和 TP 升高的主要污染源，环境保护部统计也表明畜禽污染贡献的 COD 含量超过工业废水和生活污水的总和。
由于规模化养殖能够大大提高生产效率和饲养转换率，降低成本，增加经济效益，因此，养殖业的规模化生产已然成为了一种趋势。但与此同时，规模化养殖场产生的粪便、废水也会带来一系列的环境问题，一旦粪污、废水处理利用不当将会对大气、水源和土壤等造成严重污染。其具体主要体现在以下四个方面：

（1）一些重金属如铜、锌等作为一种高效、廉价、方便的促生长添加剂在养猪业中被广泛应用，而在这些饲料添加剂中，经过消化吸收后仍有大量残留随排泄物排出体外，这些有毒有害物质不仅污染水体、土壤等周边环境，而且还通过食物链进入人体，进而潜在威胁人类健康。

（2）畜禽粪尿产生的 NH₃、H₂S 和氨等有害气体，会通过污染周围大气环境而对养殖工作人员产生危害，也会影响畜禽的生产性能、降水平。

（3）畜禽粪尿中富含富集量很大的氮、磷及 BOD 等物质，如不妥善处理，就会通过地表径流和土壤渗透进入地表水体、地下层，并在土壤中积累，导致水体富营养化和土壤污染，使土地丧失生产能力、树木枯死、绿草不生。

（4）畜禽粪尿排泄物是人畜（禽）共患传染病的主要传播载体，目前已有 200 多种被世界卫生组织和联合国粮农组织确认的“人畜共患传染病”，一旦控制不当传播人畜共患病，将直接危害人的健康。

3 江西省规模化养猪场废水治理现状

针对养殖业粪污的治理，国内外学者进行了大量的试验和实践研究，并取得了一定的成果。以猪场废水治理为例，猪场废水的处理模式主要有三种，即：还田模式[3,4]、自然处理模式[5~7]和工业化处理模式[8~10]。

对于江西省猪场废水的处理，从采用工艺技术来看，有厌氧处理、好氧处理、厌氧好氧组合处理以及氧化塘、人工湿地等自然处理。但江西省养殖场废水整体处理率仍然不高，而导致处理率低的主要原因有三点：一是畜禽养殖行业属微利行业，受到自然和市场的双重风险，企业经济效益差，没有资金投入废水处理；二是环境意识淡薄，执法不严；三是对畜禽养殖废水处理认识模糊，处理模式单一，许多人始终存在一个思维上的定式，即环保的“达标排放”思路。实际上，由于各个养殖场的自然、经济条件千差万别，养殖场的规模大小不一，环境容量有大有小，废水排放要求也不尽相同，粪污处理模式也应该多种多样。因此，对江西省规模化猪场养殖废弃物的不同处理方法进行调查研究和经济评价，总结出适合不同地区、不同规模的猪场粪污处理模式显得意义重大。

4 存在的问题

在污染物减排方面，现有大型养殖场大部分已建有一套完整的污水处理设施，因此在污染物的减排方面效果明显；而中小型养殖场，虽然建有沼气池等厌氧处理设施，但却只有少部分养殖场建有后续的好氧处理，因此，在污染物的减排方面依旧有很大的改进空间。其主要存在的主要问题具体体现为以下四个方面：

（1）江西省大多数是对猪场废水直接进行厌氧处理，回收利用沼气。而沼液则用作农家肥或者直接排放，很少达到排放标准。特别是对 NH₄⁺-N 和 P 的去除，通常厌氧消化还会导致氮转化成 NH₄⁺-N，还会因 PAO 等聚磷菌厌氧释磷使得 P 含量增多，进而造成 NH₄⁺-N 和 P 排放满足不了标准。

（2）对养猪场废水的处理多数只考虑对有机物的去除，而对 NH₄⁺-N 的去除效果不明
厌氧消化使废水有机物得到降解而 NH4+-N 却基本不降解，故降低了废水的可生化性及 C/N，给后续的好氧处理带来难度。若需提高处理效果，则必须对厌氧生物处理进行优化操作，以满足后续处理要求[11]。

（3）猪饲料中高铜高锌等重金属随粪便排出，如直接进入水体，会引起严重的重金属污染，水中铜达 0.01mg/L，对水体自净就会有明显的抑制作用；重金属浓度的增加一方面会对植物产生毒害作用，严重时可致死亡，另一方面会增加植物中相关元素的浓度，进而通过食物链进入人体和动物体内，影响人和动物的健康。

（4）抗生素能促进动物生长和对某些疾病的治疗及预防，长期以来在畜牧业中被广泛使用，且滥用情况严重[12]。而当前对畜牧业中抗生素的研究主要集中于畜禽生物体残留上[13,14]，对于伴随粪便尿液进入环境中的抗生素研究则相对较少，因而其危害性也不很清楚。

5 适宜江西省规模化养猪场废水治理可行技术推荐

为了今后更有效的治理规模化养猪场产生的废水，应根据猪场生产规模和所处周边生态环境来确定适宜的废水处理技术，不同规模的养猪场应采用不同的猪场废水处理技术[15~17]。在调查研究归纳总结的基础上，现根据猪场母猪存栏量将猪场划分为三种规模，即：小型养猪场（存栏量<500 头）、中型养猪场（500≦存栏量≦2000 头）和大型养猪场（存栏量>2000 头）。下面将就江西省三种规模养猪场现有的、典型的、处理效果好的粪污处理模式进行简介，具体见图 1~3 所示。
6 建议

（1）对于小型养猪场的废水处理，在水源缺乏的小型养殖场，适合于采用干式清粪方式进行处理；对于某些水源丰富的地方则可根据当地供水情况采用水冲粪方式进行处理，这样就能将粪便和冲洗废水充分混合以便于后续沼气池发酵产沼气。

（2）对于中型养猪场的废水处理，根据预处理方式、厌氧处理方式、好养处理方式的不同，可以分为以下两类：

Ⅰ：（水冲粪式）猪舍→格栅→沉砂集水池→搅拌均匀池→沼气池→一体化 A/O 设备→施肥或其它用途，如若当地土地资源丰富，则可以在一体化 A/O 设备后增设以氧化塘或人工湿地为主的自然生态处理，并使将处理后的水直接排放。

Ⅱ：（干清粪式）猪舍→格栅→沉砂集水池→固液分离设备→水解酸化池→IOC 反应器→SBBR 反应器→施肥或其它用途，如若当地土地资源丰富，则可以在 SBBR 反应器后增设以氧化塘或人工湿地为主的自然生态处理，并使将处理后的水直接排放。

（3）对于大型养猪场的废水处理，根据厌氧处理方式和好养处理方式的不同可以分为以下两类：

Ⅰ：（干清粪式）猪舍→格栅→沉砂集水池→固液分离设备→水解酸化池→红泥塑料厌氧池→一体化 A/O 设备→消毒→施肥或其它用途，如若当地土地资源丰富，则可以在一体化 A/O 设备后增设以氧化塘或人工湿地为主的自然生态处理，并使将处理后的水达标排放或农田灌溉。

Ⅱ：（干清粪式）猪舍→格栅→沉砂集水池→固液分离设备→水解酸化池→IOC 反应器→SBBR 反应器→消毒→施肥或其它用途，如若当地土地资源丰富，则可以在 SBBR 反应器后增设以氧化塘或人工湿地为主的自然生态处理，减轻好养工艺负担，并使将处理后的水直接达标准排放或农田灌溉。
参考文献

[1] 邓良伟. 规模化畜禽养殖废水处理技术现状探析[J]. 中国生态农业学报, 2006, 14(12): 23-26.

[2] 王亮, 陈重军, 陈英旭等. 规模化猪场养殖废水 UASB-SFSBR-MAP 处理工艺中试研究[J]. 环境科学, 2013, 34(3): 979-985.

[3] Choudhary M., Bailey L. D., Grant C. A. Review of the use of swine manure in crop production: effects on yield and composition and on soil and water quality. Waste Management & Research, 1996, 14: 581-595.

[4] Miner J. R. Alternatives to minimize the environmental impact of large swine production units. [J]. Journal of Animal Science, 1999, 77: 440-444.

[5] Stone, K.C., Poach, M.E, Hunt, P.G., et al. Marsh-pond-marsh constructed wetland design analysis for swine lagoon wastewater treatment [J]. Ecological Engineering, 2004, 23 (2): 127-133.

[6] Sklarz M Y, Gross A, Soares M I M, et al. Mathematical model for analysis of recirculating vertical flow constructed wetlands. Water Research, 2010, 44 (6), 2010-2020.

[7] 邓仕槐, 肖德林, 李宏娟等. 畜禽废水胁迫对芦苇生理特性的影响[J]. 农业环境科学学报, 2007, 26(4): 1370-1374.

[8] 万金保, 陈琳, 吴永明等.JOC-SBBR-人工湿地组合工艺在猪场废水处理中的应用[J]. 给水排水, 2011, (7): 47-51.

[9] Zhang, B., Zhao, H., Zhou, S., et.al. A novel UASB-MFC-BAF integrated system for high strength molasses wastewater treatment and bioelectricity generation [J]. Bioresource Technology, 2009, 100 (23): 5687-5693.

[10] 万金保, 何华燕, 邓香平, 等. 原位式生物膜反应器去除猪场消化液中的总磷[J]. 环境工程学报, 2011, 5(5): 1047-1050.

[11] 邓良伟, 万金保, 李淑兰, 等. 添加原水改善 SBR 工艺处理猪场废水厌氧消化性能[J]. 环境科学, 2005, 6(6): 105-109.

[12] 孙建平. 抗生素与重金属对猪场废水厌氧消化的抑制效应及其调控对策[D]. 浙江大学, 2009.

[13] 田允波. 规模化养猪生产的环境污染及防治[J]. 中国畜牧兽医, 2006, 33(5): 10-12.

[14] 苏杨, 我国集约化畜禽养殖场污染问题研究[J]. 中国生态农业学报, 2006, 14(2): 15-18.

[15] 谢文玉, 沈豪祥, 程华文, 等. 一体化 A/O 工艺对生活污水除碳脱氮效果研究[J]. 环境工程学报, 2011, 5(7): 1576-1580.

[16] 吴永明, 万金保, 熊继海, 等. IOC-SBBR 联合处理高氨氮猪场废水的快速启动与运行优化[J]. 工业水处理, 2010, 30(10): 16-19.

[17] 张冲, 黄志心, 陈家钊, 等. 红泥塑料厌氧工艺处理猪场养殖废水[J]. 农业环境科学学报, 2006, 25: 176-178.
Situation of scale pig farm wastewater Treatment and Pollution control measures in Jiangxi province

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Abstract: In Jiangxi province, the status of water pollution scale pig farms were analyzed that Swine wastewater in high concentrations of organic matter, heavy metals, antibiotics and other pollutants will bring potential hazards to air, water and soil. Summarizing and analyzing the status quo of scale pig farm wastewater treatment, then proposed for small, medium, large-scale pig farm wastewater corresponding technical feasibility recommended.

Key words: Jiangxi province; Scale pig farms; Wastewater treatment; Technical recommended
农村生活污水分散式处理研究现状及技术探讨

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摘 要：分散式污水处理研究已经成为一种新的理念，其具有投资少、简单实用、管理方便、效率高、运行成本低等许多优点，非常适合于中国农村生活污水处理。但是，污水工艺技术的选择直接影响到污水处理运行效果、稳定程度和当地的环境健康。本文综述了国内外农村分散式生活污水处理研究现状，对人工湿地、稳定塘、生物滤池、生态浮岛、厌氧生物处理工艺等主要分散式污水处理技术进行了探讨，并对常用的几种分散式污水处理技术进行了分类和比较，指出分散式生活污水处理组合工艺具有更强的适用性和应用性，是分散式生活污水处理的解决途径。

关键词：农村生活污水；分散式处理技术；人工湿地；稳定塘；组合工艺

引言

污水分散式处理是指以技术先进的小型污水处理设施实现生活污水的就近处理与利用。对于居住较为分散，受地理条件和经济因素制约的广大农村地区，相对于集中式污水处理模式，适宜的分散污水处理模式更能经济有效地保护环境和公众健康。作为国内外生活污水处理的一种新理念，分散式生活污水处理越来越受到人们的重视。

1 国内外分散式生活污水处理研究现状

国外对分散式生活污水处理研究起步较早，积累了许多经验。美国自19世纪中叶开始建设农村污水处理设施，1972年颁布了国内第一个完整的清洁水法，后来针对分散处理技术于2002年颁布了分散式污水处理系统应用手册。日本从1973年开始进行“农村村镇排水工程”建设，主要是集中处理农村生活污水，后来开发的净化槽技术在分散式生活污水中得到了广泛应用。丹麦1987年对农村生活污水排放标准进行立法，颁布了分散式生活污水处理指导守则。德国2003年起实施“分散市镇基础设施系统”项目研究，利用膜生物反应器净化偏远村镇生活污水。澳大利亚提出了菲儿脱污水处理土地利用系统。目前，欧洲和美国有20%~30%的人口使用分散污水处理设施，日本有66%的人口使用净化槽技术，分散式处理技术在这些国家已经应用成熟。

国内从20世纪80年代开始，对分散式污水处理技术同样进行了有益的探索和实践。人工湿地、稳定塘、生物滤池、厌氧好氧组合工艺在中国农村地区得到了研究和应用。太湖流域农村生活污水处理开展了以“厌氧水解+跌水充氧接触氧化+折板潜流式人工湿地组合技
术”，“塔式蚯蚓生态滤池组合技术”及“厌氧发酵+生物土壤+蔬菜种植组合技术”为核心的示范工程，取得了良好的有机物脱氮除磷效果。中国各地关于农村污水治理的规定和标准陆续出台，如：上海制定了《村镇排水工程技术规程》和《上海市农村生活污水处理技术指南》；江苏出台的《江苏省太湖水污染治理工作指南》规定太湖一级保护区农村生活污水处理率达到了70%，其他地区农村生活污水处理率达到了40%；浙江编制了《浙江省农村生活污水适用技术与实例》等。

2 散开式生活污水处理主要技术

2.1 人工湿地

人工湿地是通过模拟自然湿地，人为设计与建造的由基质、植物、微生物和水体组成的复合系统，利用“基质-微生物-植物”复合生态系统的物理、化学和生物的三重协同作用，通过过滤、吸附、沉淀、离子交换、植物吸收和微生物分解来实现对污水的净化，具有高效、低耗、投资省、适用范围广等诸多优点。常见的人工湿地主要有垂直流、表面流和潜流3种形式的人工湿地，其中用于农村生活污水处理的主要为表面流和潜流2种形式的人工湿地。

自上世纪70年代德国学者Kichuth等提出根区法理论以后，国内外学者从污染物去除机理、影响因素、基质选择、植物配置、工艺设计等各方面对人工湿地污水处理技术进行了大量的研究。彭靖君等认为降低容积负荷有利于保持系统的除污效率，二级湿地采用粒径较小的填料有助于维持系统对NH_{4}^{+}-N、TN和TP去除效果的稳定性。Hench等通过美国一个小型人工湿地连续2年的观测，发现进水负荷在19L·d^{-1}时，TSS、BOD_{5}和TN的平均去除率分别为83%、42%和55%，且第一年污染物去除效果较好。

孙亚兵等认为自动增氧型潜流人工湿地具有较强的抗冲击负荷能力，当COD、NH_{4}^{+}-N、TP进水浓度分别在132~393mg·L^{-1}、21.6~50.3mg·L^{-1}、3.6~13.2mg·L^{-1}范围内变化时，COD、NH_{4}^{+}-N、TP的去除负荷随着进水浓度的升高而增大，最高去除负荷分别为226、44.4、10.4kg·d^{-1}·hm^{-1}，相应的去除率为89.5%、88.9%、90.3%。

石蕾等通过芦苇、再力花、荻和美人蕉4种典型湿地植物的研究，发现芦苇湿地运行稳定性最好，再力花湿地具有最强的脱氮能力，美人蕉湿地能快速形成规模、实现稳定运行。自2006年至今，已研究了约100余种植物，包括水生植物、浮游植物、沉水植物等不同类型的植物，其中以水生植物为主，涵盖了多种水生植物。

2.2 稳定塘

稳定塘主要利用菌藻的共同作用，通过微生物降解、有机物吸附、有机颗粒沉降和吸附作用去除处理废水中的有机污染物质。通常稳定塘对BOD_{5}的去除率高达80%以上。磷的去除涉及底泥对PO_{4}^{3-}的吸附/解吸、有机磷氧化、磷的扩散等多机制的共同作用，但磷的主导去除机制为生物吸收还是化学沉降存在分歧。

针对稳定塘存在水力停留时间长、占地面积大、积泥严重和散发臭味、污水净化效果受自然条件影响等问题，发展了许多新型塘，如活性藻系统、水生植物塘、高效藻类塘、人工介质滤池、超深厌氧塘、移动式曝气塘等。黄翔峰等研究表明高效藻类塘能较好地净化太湖地区的农村生活污水，其存在的菌藻共生体系使塘内溶解氧浓度较高，pH值存在周期性变化，COD、NH_{4}^{+}-N和PO_{4}^{3-}的平均去除率分别为70%、90%和50%，较高流速可强化系统
统的传质效果，提高对污染物的去除能力[24]。

在稳定塘的研究中，以菌、藻活动为主体，以主要营养元素 C、N、P 迁移为线索，建立系统内各种生物、化学反应之间联系的组合工艺普遍成为国内外稳定塘采用的设计方式，如多级串联稳定塘、高级稳定塘系统、生态综合系统塘[25]。其中，高级稳定塘系统由兼性塘、高效藻类塘、藻类沉淀塘和熟化塘组成，核心是兼性塘和高效藻类塘，工艺除保留了传统稳定塘的优点外，停留时间一般只有 4~10d，能够减少臭味和出水中的藻类数量，提高除污染的负荷率和除藻能力[26]。吉祝美等通过浮床技术在稳定塘水面种植生态植物加强稳定塘的处理效果，建立生态塘对 COD、NH$_4^+$-N，TN 和 TP 去除率分别达到 55%、70%、80% 和 50% 以上，体现了较高的去除水平[27]。

2.3 生物滤池

生物滤池是由碎石或塑料制品填料构成的生物处理构筑物，通过模拟自然生态系统的原理，利用微生物、人工填料及生物膜的协同作用实现对污水的净化，其中污水中的颗粒物主要通过人工填料进行过滤，生物膜与微生物主要负责污水中的可溶性污染物[28]。目前，曝气生物滤池、塔式生物滤池、高负荷生物滤池等不同形式的生物滤池污水处理技术正广泛应用于农村生活污水处理中。杨文澜研究表明在停留时间为 3.2h、气水比为 5:1 的工艺条件下，升流式曝气生物滤池能保证出水 COD、NH$_4^+$-N、BOD$_5$、SS 达到 GB8978-1996 规定的Ⅰ级排放标准，且充分利用曝气量[29]。尹志高等研究发现塔式蚯蚓生物滤池对 BOD$_5$、NH$_4^+$-N 及 COD 平均去除率分别为 78.2%、77.8% 与 38.1%，且随着进水水质及温度的变化，出水水质稳定，具有较强的抗冲击负荷能力；但对 TN 和 TP 的去除效果不明显，平均去除率分别为 26.4% 与 24.3%，但出水水质符合 GB18918-2002 的一级 B 排放标准[30]。

2.4 生态浮岛

生态浮岛主要是通过好氧-缺氧-厌氧的代谢环境对有机物进行去除，对氨的去除主要是植物同化吸收、微生物脱氮及氨氮挥发，对磷的去除主要是植物同化吸收、微生物除磷、物理拦截及化学沉淀[31]。生态浮岛对水体中 TP、PO$_4^{3-}$、TN、NO$_3^-$、COD 有较好的去除效果，COD 和 TN 指标一般可以稳定控制在地表水环境指标 IV 类标准，而 TP 可以达到 III 类水标准[32]。但是，生态浮岛的去除效果，受水体性质、植物对污染物的吸收、气候条件等因素的影响[33]。铁柏清等开展了灯心草、菖蒲、美人蕉 3 种生态浮岛对生活污水水质处理比较研究，认为在水体交换时间为 7d 时，美人蕉对 TN 和 TP 的去除效果较好，去除率分别为 59.3% 和 69.3%[34]，说明选择适宜的浮岛植物能够提高浮岛的污水净化效果。

2.5 厌氧生物处理工艺

自 1881 年法国蒙拉斯发明污泥自动净化器以后，从早期厌氧消化工艺到目前高效厌氧反应器，厌氧技术日渐成熟和完善，适合于不同类型、不同浓度的各类污水处理[35]。厌氧消化技术在分散生活污水处理中得到了广泛的研究与应用，发展了越来越多的高速处理设备和技术，如厌氧滤池、升流式污泥床反应器、厌氧膨胀颗粒污泥床等。荷兰、巴西、哥伦比亚、印度等国家已建成生产性升流式污泥床反应器来处理生活污水。日本开发的净化槽主要处于一种厌氧-兼氧的环境条件，根据结构不同分别采用“厌氧过滤+接触曝气”、“反硝化型厌氧过滤+接触氧化”、“新型膜分离净化槽”工艺，既提高了出水质量，又起到了脱氮除磷的效果[35]。中国在农村地区推广小型装置包括无动力地埋式污水处理装置、厌氧沼气池处理技术等。
冯华军等针对厌氧工艺脱氮性能差的问题，在 ABR 厌氧处理工艺的基础上对填料式厌氧折流板反应器进行了优化，开发了一种适合用于处理分散式低浓度生活污水的无回流脱氮反应器，适用于分散式生活污水的达标处理[34]。研究进一步发现，分散式生活污水的有机负荷冲击不会对填料式厌氧折流板反应器的出水造成显著影响，COD 去除率可达 80% 以上，但在中温(18℃)和低温(10℃)条件下，反应器抗有机负荷冲击的稳定性随温度的下降而下降[35]。刘志强等采用缺氧/好氧膜生物反应器 (A/O-MBR) 试验装置进行中试试验，研究表明 A/O-MBR 工艺适用于分散聚居区的污水处理及回用，出水质能稳定达到 (GB/T18920-2002) 中的标准[36]。

3 分散式生活污水处理技术分类与比较

国内现有的适用于污水分散处理的主要技术主要分为初级处理工艺和主体处理工艺[38]。初级处理工艺包括化粪池、沉淀池等，主要用于去除部分 SS；主体处理工艺包括人工湿地、稳定塘、曝气池、生物滤池、膜反应器等，主要用于去除 COD、SS 或 N、P。根据资料和数据来源的充分性[5,8,38]，表 1 对目前常用的分散式污水处理技术进行了分类和比较。由表 1 可知，每种技术都有优缺点和适用范围，自然系统相对人工系统造价低，运行管理方便，能耗低，但是受气候条件和土地面积的限制，且出水水质不如人工系统；人工系统建造方便，投入使用快，见效快，节省占地面积但缺少灵活性，维修相对麻烦。自然生态系统中，人工湿地和稳定塘几乎无动力成本，运行管理简单，但占地面积大，处理负荷低，生态平衡较脆弱，氮磷过渡流入易造成富营养化；生物膜法和曝气生物滤池污泥产量少，系统结构简单，但出水水质不稳定且有臭味问题。人工系统中，膜生物反应器较之传统工艺出水水质好，污水可再生回用，占地面积小，但是运行管理费用高。可见，选择污水分散处理技术时，要符合当地的特点，充分利用当地优势，根据不同的处理目的和实际情况，因地制宜选择适宜的污水处理工艺。

表 1 分散式污水处理技术分类与比较

| 方法       | 处理效果              | 建设费用/m²·d⁻¹ | 运行费用/元·m⁻³ | 土地限制因素 | 适用范围                     |
|------------|------------------------|------------------|----------------|---------------|-----------------------------|
| 人工湿地   | COD > 80%, BOD₅、SS, 原体 >80%, N<60%, P > 80% | 600-800          | 0.05-0.1       | 较大           | 地势平坦、坡地、居住相对集中的中、小村庄 |
| 稳定塘     | COD > 70%, BOD₅、SS、病原体、NH₄⁺-N 去除效果较好，脱 N 除 P 差 | 500              | 0.05           | 较大           | 经济欠发达，水资源短缺，规模较小且拥有自然池塘或闲置沟渠地形的村庄 |
| 沼气净化池 | COD、BOD 达标，脱 N 除 P 效果差 | 200              | 0.10           | 非常小       | 分散式生活污水处理设施     |
| 地埋式污  | COD 10-20%, BOD₅ 20-25%, SS 60-70% | 350-400          | 0.10           | 非常小       | 适合经济基础较好，人口相对集中的中、小村庄和 |
| 人工湿地   | COD > 80%, BOD₅、SS, 原体 >80%, N<60%, P > 80% | 600-800          | 0.05-0.1       | 较大           | 地势平坦、坡地、居住相对集中的中、小村庄 |
| 稳定塘     | COD > 70%, BOD₅、SS、病原体、NH₄⁺-N 去除效果较好，脱 N 除 P 差 | 500              | 0.05           | 较大           | 经济欠发达，水资源短缺，规模较小且拥有自然池塘或闲置沟渠地形的村庄 |
| 沼气净化池 | COD、BOD 达标，脱 N 除 P 效果差 | 200              | 0.10           | 非常小       | 分散式生活污水处理设施     |
| 地埋式污  | COD 10-20%, BOD₅ 20-25%, SS 60-70% | 350-400          | 0.10           | 非常小       | 适合经济基础较好，人口相对集中的中、小村庄和 |
### 4 组合工艺

由于人工湿地、稳定塘、厌氧法、好氧法等单一技术各有优缺点和适用范围，取长补短。在实际应用中加入其他处理单元设计出由 2 种或多种技术并结合其他处理方法的组合工艺，共同处理生活污水。如沉淀池与人工湿地、生物接触氧化与人工湿地、人工湿地与稳定塘、自回流生物转盘与水生植物滤床、复合型生物净化槽与强化生态浮床、兼氧接触氧化与土地渗滤等组合工艺。陈鹏等通过研究厌氧接触工艺和改型潜流湿地的污染物去除性能，进行模块化单元优化组合出一种厌氧接触与生态组合处理工艺，COD 和 SS 平均去除率分别为 82.5%、96.5%，其中 NH4+-N 和 TP 的去除主要发生在湿地单元。赵迎迎等利用“厌氧池+射流充氧滴滤塔+人工湿地”组合工艺，进行了厌氧、好氧和人工湿地三级处理，COD、NH4+-N、TN、TP 的去除率分别可达 85%、74%、76%、80%。冉全和吕锡武研究表明，“厌氧池+接触氧化+潜流人工湿地”组合工艺 COD、NH4+-N、TN、TP 的去除率分别分别为 73%、97%、87% 和 93%。吴磊等研究表明脉冲滴滤池在水力负荷为 7.0 m3 m-2 d-1，布水周期为 20 min，回流比为 2.0 的最佳运行条件下，与水力停留时间为 12 h 的前置水解池，以及水力负荷 50cm d-1 的后置人工湿地组合运行时，水解池+脉冲滴滤池+人工湿地组合工艺对 COD、TN 和 TP 的平均去除率分别达 91%、95% 和 95%。以上结果表明，这些组合工艺能以较低的处理成本，取得良好的污染物去除效果，获得稳定的出水水质，具有更强的适用性和应用性。

### 5 结语

分散式污水处理工艺已经成为低密度、人口分散居住的广大农村地区生活污水处理优先选择的工艺，但污水工艺技术的选择是否得当直接影响到污水处理运行效果和稳定程度，也对工程基建投资、运行费用、管理操作等产生根本影响。中国农村幅员辽阔，农村地区的生态环境、经济发展水平各异，在实际应用中应根据自然环境、地形条件、人口规模、投资情况等因素，因地制宜选择污水处理工艺，充分实现成本的最小化和效用的最大化，促进可持
续性。此外，政府需要出台设计和管理规范，合理确定农村生活污水排放控制标准和污水处理设施建设标准，加大资金扶持力度，完善长效管理制定，通过宣传和教育发挥公众的参与度，促进农村分散式生活污水处理可持续性，真正的改善农村的生态环境。

参考文献

[1] Lens P, Zeeman G, Lettinga G. 分散式污水处理和再利用—概念、系统和实践. 北京: 化学工业出版社, 2004.

[2] Hlstrom D, Jonsson L. Evaluation of small waste water treatment systems. Water Science and Technology, 2003, 48(11): 61-68.

[3] Massoud MA, Tarhini A, Nasr JA. Decentralized approaches to wastewater treatment and management: Applicability in developing countries. Journal of Environmental Management, 2009, 90(1): 652-659.

[4] Chen Jinming. 美国管理分散污水处理系统的政策和经验. 中国给水排水, 2004, 20(6): 104-106.

[5] 李无双, 王洪阳, 潘淑君. 农村分散式生活污水现状与处理技术进展. 天津农业科学, 2008, 14(6): 75-77.

[6] 刘志强. 基于缺氧-好氧膜生物反应器的分散聚居区污水处理及回用研究. 西安: 西安建筑科技大学, 2010.

[7] Hans Brix. Danish guidelines for small-scale constructed wetland systems for onsite treatment of domestic sewage[C]. Proceedings of the 9th International Conference on Wetland Systems for Water Pollution Control, Avignon, France, 2004: 1-8.

[8] 张家伟, 周志勤. 浅析农村生活污水处理分散式处理适用技术. 环境科学与管理, 2011, 36(1): 95-99.

[9] 李先宁, 吕锡武, 吕海明. 农村生活污水处理技术与示范工程研究. 中国水利, 2006, 17: 19-22.

[10] 张蕾. 通州区农村生活污水处理适用技术的调查与分析. 天津: 天津大学, 2010.

[11] 李杰, 钟成华, 邓春光. 人工湿地研究进展. 安徽农业科学, 2007, 35(6): 1778-1780.

[12] Hencha K R., Bissonnette G K., Sextone A J., et al. Fate of physical, chemical, and microbial contaminants in domestic waste water following treatment by small constructed wetlands. Water Research, 2003, 37: 921–927.

[13] 于峰. 农村分散式生活污水的现状及适合的处理技术. 西南给排水, 2012, 34(6): 28-30.

[14] Kichuth R. Degradation and incorporation of nutrients from rural wastewaters by plant rhizosphere under Limnis Conditions[M]. Utilization of Manure by Land Spreading, Commission of the Europe Communities. Back-guys Publishers, Leiden, the Netherlands, 1977, 243-335.

[15] 曹笑笑, 吴庆国, 张仲明. 人工湿地设计研究进展. 湿地科学, 2013, 11(1): 121-129.

[16] 常世珪, 钟云, 郭正. 二级串联人工湿地处理农村生活污水的脱氮除磷研究. 中国给水排水, 2007, 23(1): 88-96.

[17] 孙亚兵, 冯景伟, 张国昌. 人工湿地处理农村生活污水的研究. 环境科学学报, 2006, 26(3): 404-408.

[18] 罗蕾, 杨Streams. 人工湿地植物量及其对净化效果影响的研究. 生态环境学报, 2010, 19(1): 28-33.
何小莲,李俊峰,何新林,等.稳定塘污水处理技术的研究进展.水资源与水工程学报,2007,18(5):75-77.

Maynard H E, Ouki S K, Williams S C. Tertiary lagoons: A review of removal mechanisms and performance. Water Research, 1999, 33(1):1-13.

刘华波,杨海真.稳定塘污水处理技术的应用现状与发展.天津城市建设学院学报,2003,9(1):19-22.

Silva S A, Oliverira R D, Soares J. Nitrogen removal in pond systems with different configurations and geometries[J]. Water Science and Technology, 1995, 31(12):321-330.

Hong Wang, Adhityan Appan, John S Gulliver. Modeling of phosphorus dynamics in aquatic sediments: I-model development[J]. Water Research, 2003, 37(16):3928-3938.

黄翔峰,池金萍,何少林,等.高效藻类塘处理农村生活污水研究.中国给水排水,2006,22(5):35-39.

刘华波,杨海真.稳定塘污水处理技术的应用现状与发展.天津城市建设学院学报,2003,9(1):19-22.

Silva S A, Oliverira R D, Soares J. Nitrogen removal in pond systems with different configurations and geometries[J]. Water Science and Technology, 1995, 31(12):321-330.

香港,池金萍,何少林,等.高效藻类塘处理农村生活污水研究.中国给水排水,2006,22(5):35-39.

[24] 张巍.生态稳定塘系统处理农村及小城镇生活污水的现状及前景.江苏农业科学,2003,41(2):329-332.

郭志宏,夏振平.农村及小城镇污水的稳定塘处理技术.科技信息,2007,11:292.

[26] 郭志宏,夏振平.农村及小城镇污水的稳定塘处理技术.科技信息,2007,11:292.

[27] 吉祝美,李通林,吕锡武,等.生态塘处理农村生活污水的效果分析.江苏环境科技,2007,20(5):39-41.

[28] 金鑫.杨学斌.生态滤池污水处理技术应用与研究.科技与企业,2013:142.

[29] 杨文澜.升流式曝气生物滤池处理农村生活污水性能参数的研究.安徽农业科学,2008,36(25):11047-11048,11059.

[30] 尹志高,陆志波,杨健,等.蚯蚓生物滤池处理农村分散生活污水效果研究.四川有性金属,2011,4:59-64.

[31] 张增胜.农村分散式生活污水处理适用技术及机理研究.上海:东华大学,2010.

[32] 宋恩铭,张振明,余新涛,等.植物人工浮岛对湿地污染物净化效果研究.水处理技术,2011,37(10):121-124.

[33] 武琳慧,吴林林,黄民生等.人工浮床及其在污染水体治理中应用进展.净水技术,2006,25(4):8-10.

[34] 铁柏清,李希,李杰峰.3种植物人工浮岛对生活污水水质动态净化特性的比较.环境工程学报,2010,4(7):1566-1570.

[35] 陈鹏.分散式生活污水厌氧接触与生态组合处理工艺试验研究.山东:山东建筑大学,2010.

[36] 冯华军.分散式生活污水处理工艺开发及机理研究.浙江:浙江大学,2008.

[37] 冯华军,汪美贞,黄宝成,等.CABR处理分散式生活污水抗短期有机负荷潜能.环境工程学报,2012,6(11):4053-4058.

[38] 齐瑶,常妙,小城镇和农村生活污水分散处理的适用技术.中国给水排水,2008,24(18):24-27.

[39] 吴树彪,胡静,霍旭,等.家庭人工湿地组合系统处理农村生活污水的试验研究.水处理技术,2009,35(3):91-98.

[40] 向敏.农村生活污水处理的组合工艺试验研究.安徽农业科学,2008,36(2):677-678.

[41] 付融冰,杨海真,顾国维,等.潜流人工湿地对农村生活污水氮去除的研究.水处理技术,2006,3(1):18-21.
Present Status and Technology on Decentralized Treatment of Domestic Sewage in Rural Areas

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Abstract: Decentralized treatment of domestic sewage has become a new idea. Due to many advantages such as small investment, convenience of management, high purification efficiency, and low maintenance costs, etc, it is suited for rural domestic sewage treatment. However, the choice of techniques of sewage treatment is directly related to the effects of sewage treatment and the environmental health in an area. In this paper, the present status of treatment of rural domestic sewage both in China and abroad were reviewed, and several technologies of decentralized treatment domestic sewage were introduced, such as constracted wetlands, stabilization pond, artificial floating island, biological filte and anaerobic biological treatment technology. Based on the comparison of advantages and disadvantages of many decentralized treatment technologies being used in China and abroad, their treatment effect, environmental and economic conditions were discussed. Finally, we suggested that, hybrid of different processes has stronger applicability for decentralized treatment domestic sewage, which promoting decentralized treatment facilities in the future.

Key words: rural domestic sewage; decentralized treatment technology; constracted wetlands; stabilization pond; hybrid processes
鄱阳湖不同典型年份水环境质量分析

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摘要：本文选取 2010 年、2005 年、2003 年三个不同年份，分别代表丰水年、平水年、枯水年，按照入湖、湖中、出湖三个部分，分别针对上述 3 年的监测成果进行分析评价，结果表明，按评价次数统计，2010 年入湖主要径流水质较好，Ⅰ～Ⅲ类水占 90%，湖中Ⅰ～Ⅲ类水占 45%，主要污染物为总磷、氨氮；出湖口Ⅰ～Ⅲ类水占 42%，集中在5月至9月，主要污染物为总磷。2005 年入湖河流按评价次数统计，Ⅰ～Ⅲ类水占 73%，主要污染物为氨氮、总磷。湖中Ⅰ～Ⅲ类水占 64%，主要污染物为总磷、氨氮。出湖湖口断面均为Ⅰ～Ⅲ类水。2003 年入湖河流按评价次数统计，Ⅰ～Ⅲ类水占 77%；主要污染物为氨氮、总磷。湖中Ⅰ～Ⅲ类水占 87%，主要污染物为总磷。出湖湖口断面均为Ⅰ～Ⅲ类水。

关键词：鄱阳湖；典型水平年；水质分析

1 前言

作为中国最大的淡水湖泊，鄱阳湖的水质在五大淡水湖中是比较好[1]。但随着鄱阳湖生态经济区的发展，入湖污染物质日益增长，而 2003 年以来鄱阳湖枯水期的水位连创新低，其持续时间又延长，湖区蓄水的锐减加重了湖水的污染负荷，对水质安全构成严峻挑战[2]。鄱阳湖是典型的过水性、季节性、吞吐型湖湖湖[3]，具有“高水是湖，低水似河”的独特形态，丰、枯水期湖泊面积、容量相差大。丰水期湖水漫滩，湖面扩大，水量增多，水环境容量增大；而湖水漫滩后，洲滩植被可吸收降解湖水中污染物，湖泊的生物自净能力增强；在枯水期，流速减缓，可能水体物理自净、化学自净能力减弱。而在枯水期，湖水落槽，洲滩显露，湖面缩小，水环境容量减小，洲滩植被也无从降解湖水中污染物，但湖水的流速加快，与河道无异，水体的物理自净、化学自净能力增强。鄱阳湖水位变化对水质产生多重影响，有必要对鄱阳湖不同水期下的水环境质量进行实地调查分析。

2 材料与方法
2.1 研究区域

鄱阳湖是中国长江中游典型的通江湖泊，是中国第一大淡水湖，也是国际重要湿地，在维系区域水量平衡与生态安全方面发挥着重要作用[4-6]。鄱阳湖位于东经 115°50′-116°44′，北纬 28°25′-29°45′，在江西省北部长江中下游南岸。鄱阳湖上游承接赣江、抚河、信河、饶河、修河五条主要河流来水，经湖区调蓄后由湖口注入长江，是一个季节性较强的吞吐型湖泊。鄱阳湖湖面以松门山为界，分为南北两部分，北面为入江水道，长 40 km, 宽 3 ～5 km，最窄处约 2.8 km；南面为主湖体，长 133 km，最宽处达 74 km。鄱阳湖地理位置及监测站点地位见图 2.1。鄱阳湖水面积与库容随季节变幅较大。湖区多年平均水位 13.30m，对应水面积与库容分别为 2291.9 km²与 2.1×10⁹ m³。据多年观测，鄱阳湖水位变化受五河及长江来水双重影响，4～6 月随五河洪水入湖而水位上涨，7～9 月因长江洪水顶托或倒灌而维持高水位，10 月～次年 3 月为低水位期。鄱阳湖水位年内变幅大，多年（1956～2000 年）最高最低水位差达 10.34 ～16.69 m，有 77.8%的年份最高水位发生在 6、7 月份，79.3%的年份最低水位发生在 12 月和 1 月。

![图 2.1 鄱阳湖地理位置及监测断面位置图](image)

2.2 监测与分析方法

鄱阳湖入湖、湖区、出湖监测断面每月开展一次监测。主要入湖河流设立控制断面 8 处：赣江（外洲）、抚河（李家渡）、信江（梅港）、修河（永修）、饶河昌江（渡峰坑）、饶河乐安河（石镇街）、西河（石门街）、博阳河（梓坊）。湖区设立监测断面 18 处：信江西支（N0.1），抚河口（N0.2），赣江南支（N0.3），康山（N0.4），信江东支（N0.5），乐安河口（N0.6），昌江口（N0.7），鄱阳（N0.8），龙口（N0.9），瓢山（N0.10），棠阴（N0.11），都昌（N0.12），赣江主支（N0.13），修河口（N0.14），蚌湖（N0.15），渚溪口（N0.16），星子
（N0.17），蛤蟆石（N0.18）。出湖设立出湖控制断面湖口（N0.19），布设垂线 3 条。

监测项目：采集断面表层水样，监测水温、pH 值、溶解氧、高锰酸盐指数、氨氮、总磷、总氨、铜、锌、氟化物、硒、砷、汞、镉、六价铬、铅、氰化物、挥发性酚; 主要入湖河流、出湖控制断面在监测水质的同时，同步进行水量监测。

3 结果与讨论

3.1 丰水年 2010 年鄱阳湖水环境质量

3.1.1 入湖河流水质状况

根据 2010 年监测成果，按主要入湖河流达标次数统计，8 条主要入湖河流（饶河分两支入湖）共监测 96 次，Ⅰ～Ⅲ类水占 90%，其中赣江、信江、修河、饶河昌江、西河、博阳河等 6 条河流全年 12 个月均达标，入湖水质总体较好。抚河除 5 月外均达标，Ⅰ～Ⅲ类水占 92%，主要污染物为氨氮。饶河乐安河除 2 月、3 月、9 月外均不达标，Ⅰ～Ⅲ类水占 25%，水质较差，主要污染物为氨氮、总磷。

表 3.1.1 2010 年主要入湖河流水质类别统计表（按达标次数）

|         | 赣江 | 抚河 | 信江 | 修河 | 昌江 | 乐安河 | 西河 | 博阳河 |
|---------|------|------|------|------|------|--------|------|--------|
| Ⅰ～Ⅲ类 | 100% | 92%  | 100% | 100% | 100% | 100%   | 100% | 100%   |
| 主要污染 |      |      |      |      |      |        |      |        |
| 月份 | 5 月 |      |      |      |      |       |      |        |
| 主要污染物 | 氨氮 |      |      |      |      |        |      |        |

3.1.2 湖区和出湖水质状况

根据监测资料，按监测评价次数统计，湖区 18 个监测断面全年共监测 192 次，Ⅰ～Ⅲ类水占 45%，主要污染物为总磷、氨氮。其中Ⅱ类水占 11%，Ⅲ类水占 33%，Ⅳ类水占 30%，Ⅴ类水占 19%，劣 V 类水占 7%。见图 3.1.2-1。

![图 3.1.2-1 2010 年湖区水质类别比例图](image)

5-9 月 I～Ⅲ类水比例较高，7 月份最高，Ⅰ～Ⅲ类水占 100%；2 月份最低，Ⅰ～Ⅲ类水占 7%。见图 3.1.2-2。
按湖区监测断面代表水域面积统计，2010 年湖区 I ～ III 类水占 71%，主要污染物为总磷、氨氮。其中汛期 I ～ III 类水占 78%，非汛期 I ～ III 类水占 9%，远低于汛期。见表 3.1.2。湖泊水质基本呈现沿主航道方向，从东南湖区到北部通江水道，水质逐渐好转的趋势；表明湖区水质主要受上游来水（入湖河流、航道上游）携带污染物影响，沿主航道水流方向，污染物逐渐稀释，水质好转。

表 3.1.2 2010 年湖区 I ～ III 类水面积比例表

| 年份 | I ～ III 类水面积比例 | 劣于 III 类水面积比例 | 主要污染物 |
|------|----------------------|----------------------|------------|
| 2010 年 | 全年 | 71% | 29% | 总磷、氨氮 |
| | 汛期 | 78% | 22% | 总磷、氨氮 |
| | 非汛期 | 9% | 91% | 总磷、氨氮 |

出湖口按监测评价次数统计，出湖湖口断面全年共监测 12 次， I ～ III 类水占 42%，集中在 5 月至 9 月；其他月份均劣于 III 类水，主要污染物为总磷。其中 IV 类水占 42%，V 类水占 16%。按监测水量统计，湖口断面水量 I ～ III 类水占 54%，集中在 5 月至 9 月；其他月份均劣于 III 类水，主要污染物为总磷。

3.2 平水年 2005 年鄱阳湖水环境质量

3.2.1 入湖河流水质状况

根据 2005 年监测成果，按评价次数统计，主要入湖河流 I ～ III 类水占 73%，入湖水质总体较好。其中赣江、饶河昌江、博阳河等 3 条河流全年均为 I ～ III 类水；修河、抚河、信江等 3 条河流除少数月份外均为 I ～ III 类水， I ～ III 类水分别占 92%、83%、75%，主要污染物为总磷、氨氮；饶河乐安河全年均劣于 III 类水，主要污染物为氨氮、总磷。
表 3.2.1 入湖河流水质类别统计表（按达标次数）

|         | 赣江 | 抚河 | 信江 | 修河 | 昌江 | 乐安河 | 博阳河 |
|---------|------|------|------|------|------|--------|--------|
| Ⅰ～Ⅲ类 | 100% | 83%  | 75%  | 92%  | 100% | 0%     | 100%   |
| 主要污染月份 | 8 月、11 月 | 1 月、10 月、11 月 | 2 月 | 全年 |
| 主要污染物 | 氨氮 | 总磷 | 总磷 | 氨氮 |

3.2.2 湖区和出湖水质状况

按评价次数统计，湖区 18 个监测断面全年共监测 54 次，Ⅰ～Ⅲ类水占 64%，主要污染物为总磷、氨氮。其中Ⅱ类水占 2%，Ⅲ类水占 62%，Ⅳ类水占 19%，Ⅴ类水占 17%。见图 3.2.2-1。

图 3.2.2-1 2005 年湖区水质类别比例图

7 月份Ⅰ～Ⅲ类水所占比例最高，为 82%；11 月份最低，Ⅰ～Ⅲ类水占 28%。按断面代表水域面积统计，湖区Ⅰ～Ⅲ类水面积占 85%，主要污染物为总磷、氨氮。鄱阳湖出湖湖口断面，按监测评价次数统计，Ⅰ～Ⅲ类水占 100%。

3.3 枯水年 2003 年鄱阳湖水环境质量

3.3.1 入湖河流水质状况

根据监测成果，按评价次数统计，2003 年 7 条主要入湖河流（饶河分两支入湖）共监测 66 次，Ⅰ～Ⅲ类水占比 77%，入湖水质总体较好。其中赣江、修河、抚河等 3 条河流全年均为Ⅰ～Ⅲ类水；昌江、抚河、信江等 3 条河流除少数月份外均为Ⅰ～Ⅲ类水，占 75%以上，主要污染物为氨氮；饶河乐安河除 1 月、3 月、4 月、5 月，其他月份均优于Ⅲ类水，主要污染物为氨氮、总磷。
### 表 3.3.1 2003 年入湖河流水质类别统计表（按达标次数）

|       | 赣江 | 抚河 | 信江 | 修河 | 昌江 | 乐安河 | 博阳河 |
|-------|------|------|------|------|------|--------|--------|
| I~III类 | 100% | 75%  | 75%  | 100% | 83%  | 33%    | 100%   |
| 主要污染月份 | 5月、7月、8月 | 5月、10月、12月 | 12月 | 2月、6月、7月、8月、9月、10月、11月、12月 |
| 主要污染物 | 氨氮 | 总磷 | 氨氮 | 氨氮 |

赣江、抚河、博阳河全年均为I类或II类水；信江、昌江、抚河以I~III类水为主，占75%以上；乐安河水质较差，以劣于III类水为主，占67%。

![图 3.3.1 2003 年主要入湖河流水质类别比例图](image)
3.3.2 湖区和出湖水质状况

按监测评价次数统计，湖区 18 个监测断面全年共监测 54 次，Ⅰ～Ⅲ类水占 87%，主要污染物为总磷。其中Ⅱ类水占 39%，Ⅲ类水占 48%，Ⅳ类水占 13%。见图 3.3.2。

具体到 3 月、7 月、11 月水质类别组成可见，7 月份Ⅰ～Ⅲ类水所占比例最高，Ⅰ～Ⅲ类水占 94%；11 月份最低，Ⅰ～Ⅲ类水占 72%。按断面代表水域面积统计，Ⅰ～Ⅲ类水占 99%，主要污染物为总磷。鄱阳湖出湖断面湖口，按监测评价次数统计，Ⅰ～Ⅲ类水占 100%。

4 结论

本章选取 2010 年、2005 年、2003 年三个不同年份，分别代表丰水年、平水年、枯水年，按照入湖、湖区、出湖三个部分，分别针对上述 3 年的监测成果进行分析评价，结果如下：

2010 年入湖主要径流水质较好，按评价次数统计，Ⅰ～Ⅲ类水占 90%；按评价水量统计，8 条主要入湖河流（饶河分两支入湖）Ⅰ～Ⅲ类水流量占 95%；主要污染物为氨氮、总磷。湖区按评价次数统计，Ⅰ～Ⅲ类水占 45%；按断面代表水域面积统计，Ⅰ～Ⅲ类水占 71%；主要污染物为总磷、氨氮。出湖湖口断面，按评价次数统计，Ⅰ～Ⅲ类水占 42%，集中 5 月至 9 月，主要污染物为总磷。

2005 年按评价次数统计，Ⅰ～Ⅲ类水占 73%；按评价水量统计，Ⅰ～Ⅲ类水占 87%，主要污染物为氨氮、总磷。湖区按评价次数统计，Ⅰ～Ⅲ类水占 64%；按断面代表水域面积统计，Ⅰ～Ⅲ类水占 85%；主要污染物为总磷、氨氮。出湖湖口断面均为Ⅰ～Ⅲ类水。

2003 年按评价次数统计，Ⅰ～Ⅲ类水占 77%；按评价水量统计，Ⅰ～Ⅲ类水占 86%，主要污染物为氨氮、总磷。湖区按评价次数统计，Ⅰ～Ⅲ类水占 87%；湖区按断面代表水域面积统计，Ⅰ～Ⅲ类水占 99%；主要污染物为总磷。出湖湖口断面均为Ⅰ～Ⅲ类水。
Water Quality Analysis for Poyang Lake

in Typical Years

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Abstract: The paper chose three different years as high-water year, common-water year and dry-water year, based on inflowing rivers, lake district, lake outlet three parts, the monitoring results was analyzed. According to the statistics of evaluation, in 2010, for inflowing rivers, lake district, lake outlet, water of category Ⅰ-Ⅲ accounted for 90%, 45% and 42% respectively. Pollutants of lake district primarily were TP and NH3-N, while only TP in outlet. In 2005, water of category Ⅰ-Ⅲ in inflowing rivers, lake district, lake outlet accounted for 73%, 64% and 100%. Pollutants of inflowing rivers and lake district were TP and NH3-N; in 2003, water of category Ⅰ-Ⅲ in inflowing rivers, lake district, lake outlet accounted for 77%, 87% and 100% respectively. Pollutants of inflowing rivers were TP and NH3-N, while was TP in lake district.

Keywords: Poyang Lake; typical years; Water quality analysis
鄱阳湖候鸟保护区微生物污染季节变化特征

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摘 要: 为了解鄱阳湖候鸟保护区微生物污染状况及水体使用功能, 给湖泊研究和疾病防控提供理论依据, 选择具有典型代表性的蚌湖作为研究对象。于 2012-2013 年丰水期和枯水期,根据蚌湖水流扩散方向设置三个采样点 (入湖口、湖中心、出湖口), 主要对 4 种指示菌（菌落总数、总大肠菌群、粪大肠菌群、肠球菌）和 3 种致病菌（沙门氏菌、金色葡萄球菌、志贺氏菌）进行检测和分析。研究表明：（1）丰水期、枯水期除了粪大肠菌群菌群（对数值 2.40±0.31~3.23±0.35）统计学无差异外，菌落总数（对数值 2.77±0.17~4.38±0.62）、总大肠菌群（对数值 3.02±0.31~4.77±0.18）、肠球菌（对数值 2.07±0.25~3.67±0.43）差异均具有统计学意义（P<0.05）。 （2）除菌落总数外，其它三种指示菌对三种致病菌均呈正相关且有统计学意义（P<0.05）。 （3）蚌湖丰水期细菌总数污染程度不低于枯水期，均受到粪便污染，丰水期粪便污染主要来自人类，而枯水期粪便污染主要来自动物。两个时期均不符合饮用水源和娱乐用水要求，在三个采样点检测出不同程度致病菌。

关键词: 蚌湖; 指示菌; 致病菌; 污染

鄱阳湖候鸟保护区主要部分位于江西省永修县境内，面积22400公顷，包括大湖池、蚌湖等9个湖泊及周围湖滩草洲，其中蚌湖面积大、基本保持自然状态、珍禽富集而成为鄱阳湖国家级自然保护区的核心保护洼地，枯水期仍保有湖水，属封闭式水体[1]，因而最具代表性，又便利观测，所以选择了蚌湖为研究对象。该保护区是世界保护、研究鸟类的重要基地。目前，地表水中化学污染物和致病微生物的污染日趋严重，其中致病微生物污染引起的水质安全问题尤为突出，美国2000 年的水质报告也显示[2]，微生物污染是影响水质主要原因之一。水环境受各种致病微生物污染引起多种介水传染病，尤其是肠道传染病的发生[3]。国外研究指出，40% 的河流及河口的水质难以达到水环境标准是由于病原微生物所致[4]。我国缺乏对河湖水体中的病原或指示微生物进行长期而系统的调查研究，仅有少数相关文献的报道[5]。为了使候鸟有个更舒适的环境过冬、为周围的居民意识到到水体污染的严重性，为该湖泊污染治理和疾病防控提供理论指导和科学依据，于2012-2013年丰水期、枯水期在候鸟保护区蚌湖段进行微生物污染调查，根据调查结果对水体污染状况、使用功能进行评价。

1 材料与方法

1.1 仪器与试剂

GPS手持机-eXplorist 500，便携式pH测定仪、恒温培养箱、高压灭菌锅、超净工作台、

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玻璃培养皿、平板计数琼脂培养基、结晶紫中性红胆盐琼脂、肠球菌显色培养基、M-FC培养基、沙门菌显色培养基、志贺菌显色培养基、豆粉琼脂、脱纤维羊血、四硫磺酸盐煌绿增菌液、GN增菌液、7.5%氯化钠肉汤，各种鉴定致病菌的试剂。

1.2 水样采集

根据蚌湖的水流情况，确定蚌湖的入湖口、湖中心、出湖口，入湖口3个采样点，中心水域4个采样点，出湖口3个采样点，每个采样点一次采集2个水样。在枯水期（2013年3月）、丰水期（2012年7月）共采集20个水样，并用GPS定位确定在枯水期和丰水期采样点的一致性。采样现场记录水样的温度、pH值、水深，将采集的水样放入放有冰袋的保温箱中保存并在4h内进行检测。

1.3 微生物检测方法

1.3.1 指示菌的检测

菌落总数、总大肠菌群用单层琼脂平板计数法，参照GB/T 5750—2006《生活饮用水标准检验方法》中的滤膜法进行检验，检验项目包括粪大肠菌群和肠球菌的检测根据文献[6]进行，指示菌指标均定量检测。

1.3.2 常见致病菌的检测

分别选择相应的增菌培养液和显色培养基对沙门菌、志贺菌、金色葡萄球菌进行检测，致病菌为定性检测。

1.3 统计方法

采用SPSS19.0软件进行统计学分析。对蚌湖丰水期和枯水期的一些指标的差异进行t检验；采用Spearman秩相关分析指示菌之间及致病菌的相关性，以P<0.05为差异有统计学意义。

2 指示菌与致病菌的评价方法

2.1 水体污染程度的评价标准
菌落总数采用污水生物系统进行评价，寡污带，水质清洁：\( \text{ACC} \leq 10^2 \text{ cfu/ml} \); \( \beta \)-中污带，轻度污染：\( 10^2 \text{ cfu/ml} < \text{ACC} \leq 10^4 \text{ cfu/ml} \); \( \alpha \)-中污带，中度污染：\( 10^4 \text{ cfu/ml} < \text{ACC} \leq 10^6 \text{ cfu/ml} \);多污带，重度污染：\( \text{ACC} > 10^6 \text{ cfu/ml} \)。

2.2 水体使用功能的评价标准

采用《生活饮用水水源水质标准》[8] CJ3020—1993 规定的一级水源水总大肠菌群\( \leq 1000 \text{ 个/L} \), 二级水源水总大肠菌群\( < 10000 \text{ 个/L} \)进行评价。一级水源水:水质良好。地下水只需消毒处理, 地表水经简易净化处理(如过滤)、消毒后即可供生活饮用者。二级水源水:水质受轻度污染。常规净化处理(如絮凝、沉淀、过滤、消毒等), 其水质即可达到 GB5749 规定,可供生活饮用者。

借鉴美国《水质质量标准》[9] 允许身体与水体直接接触的娱乐用水标准(大肠埃希菌\( \leq 576 \text{ CFU/100mL} \)和(粪大肠菌群\( \leq 151 \text{ CFU/100mL} \))两项进行评价, 有一项不符合即为不符合。

2.3 粪便污染判断

如果粪大肠菌群/肠球菌(Fc/Fs) 比值为 4 或更大, 就意味着污染源在来自人类; 比值小于 0.7,则表明是动物性污染。评价标准见表 1

| FC/FS比值 | 粪便污染源       |
|----------|------------------|
| ＞4.0    | 人类污染         |
| 2.0-4.0  | 主要是人类污染的混合污染 |
| 0.7-2.0  | 主要是动物污染的混合污染 |
| ＜0.7    | 动物污染         |

2.4 水体安全性评价

根据致病菌的检出情况评价水体的安全性。

3 结果与分析

3.1 丰水期、枯水期的水温

丰水期、枯水期的水温平均值分别为\( (30 \pm 0.2) \text{ ℃} \)、\( (17 \pm 0.6) \text{ ℃} \)。差异具有统计学意义\( (t=20.930, P < 0.05) \)。

3.2 丰水期、枯水期的pH值

丰水期、枯水期各采样点的pH值均在7.8, 差异没有统计学意义

3.3 丰水期、枯水期的指示菌

各种指示菌数量级跨度比较大，不适合进行统计分析，将其转换为以10为底的对数。不同时期4种指示菌的均值做配对样本t检验见表 2。蚌湖各指示菌均呈现出枯水期＞丰水期,
除了粪大肠菌群在丰水期和枯水期差异没有统计学意义外，其余各指示菌差异均具有统计学意义。

表2 丰、枯水期各指示菌对数均值与差异

| 项目 | 菌落总数 | 总大肠菌群 | 粪大肠菌群 | 肠球菌 |
|------|----------|------------|------------|--------|
| 丰水期 | 2.77±0.17 | 3.02±0.31 | 2.40±0.31 | 2.07±0.25 |
| 枯水期 | 4.38±0.62 | 4.77±0.18 | 3.23±0.35 | 3.67±0.43 |
| 统计结果 | t=4.4 | t=4.8 | t=1.27 | t=6.07 |
|      | P<0.05 | P<0.05 | P>0.05 | P<0.05 |

3.4 粪便污染情况

大肠埃希菌可作为水体粪便污染的量化指标，水体检出大肠埃希菌证明受到粪便污染，大肠埃希菌含量越高，粪便污染越严重，因为粪大肠菌群主要是由埃希菌属的大肠埃希菌组成，所以可用粪大肠菌群判断粪便污染情况。丰水期除了中心水域粪便污染主要来自于动物污染混合污染外，入湖口和出湖口主要是人类粪便污染的混合物。枯水期入湖口粪便污染主要受人类的影响，中心水域、出湖口的粪便污染均来自于动物。

3.5 指示菌之间的相关性

表3 指示菌之间及水温的相关性（r值）

| 指标 | 菌落总数 | 总大肠菌群 | 粪大肠菌群 |
|------|----------|------------|------------|
| 总大肠菌群 | 0.771 a | - | - |
| 粪大肠菌群 | 0.892 a | 0.714 | - |
| 肠球菌 | 0.771 a | 0.998 b | 0.741 |

注：经Spearman秩相关分析 aP<0.05, bP<0.01

对20份水样进行Spearman秩相关分析，结果见表5。菌落总数与总大肠菌群、粪大肠菌群、肠球菌指标之间均呈正相关且具有统计学意义（P<0.05）。总大肠菌群与肠球菌呈明显正相关且具有统计学意义（P<0.01），与粪大肠菌群呈正相关无统计学意义。粪大肠菌群与肠球菌呈正相关无统计学意义。

3.6 水体评价

丰水期蚌湖水属于轻度污染，污染程度：湖中心＞出湖口＞入湖口。位于赣江北支和修水两河交汇三角洲地带的蚌湖丰水期，污染物来源相对较多，入湖口在丰水期与鄱阳湖连成一片，水体交换量大，水质良好。湖中心水温较高，适合微生物生长，溶解氧较低，水体流动不大，有机物污染积累比较多。该水域受到粪便污染，主要是人类粪便污染，兼有动物粪便污染，污染程度：出湖口＞湖中心＞入湖口。蚌湖边上杨柳津河携带的部分周边城镇生活污水可以地表流至出湖口，则出湖口处受到的粪便污染较为严重。蚌湖水入湖口和中
心水域符合二级水源要求，出湖口不符合水源水要求，三个采样断面均不符合娱乐用水要求。在中心水域、出湖口检测出沙门氏菌检、金色葡萄球菌，志贺氏菌。

枯水期蚌湖水受到轻度污染，污染程度：入湖口＞中心水域＞出湖口。鄱阳湖枯水期水10月～翌年3月水落滩出，鱼、虾、螺、蚌及各种水草丰富，是候鸟越冬栖息地。有很多鱼、虾、螺等各种残体，有机物污染严重。入湖口处草洲水草丰富，每都有人割草作燃料，芦苇作为造纸原料。割草期间人类活动频繁，自然生活污水就污染了蚌湖。该水域受到粪便污染，主要是动物和人类粪便污染，污染程度：入湖口＞中心水域＞出湖口。入湖口处有很多候鸟在那栖息再加上周围村庄水牛几乎是随湖放养，粪便污染相对较大。各断面均不符合饮用水源和娱乐用水要求。在入湖口、中心水域都检测出沙门氏菌，出湖口检测出志贺氏菌。

4 结论
通过对蚌湖三个采样点在丰水期和枯水期的一些微生物的检测，发现蚌湖存在一定的微生物污染。枯水期污染较为严重，枯水期候鸟迁徙，周围居民放养家畜等产生了比较严重粪便污染。有关部门要加强污染治理与肠道传染病的防控。细菌总数对三种致病菌都有一定的指示作用。

参考文献
[1] 胡春华.2010. 鄱阳湖水环境特征及演化趋势研究[D].南昌: 南昌大学.
[2] Cole D，Long SC，Sobsey MD. Evaluation of F+RNA and DNA coliphages as source—specific indicators of fecal contamination in surface waters[J]. APPL Environ Microbiol，2003，69：6507—6514.
[3] 任金法. 饮用水水源污染对人体健康的威胁及安全饮水的对策[J]. 中国卫生检验杂志，2009，19（4）：942—944.
[4] James E S，Joyce M P. Assessment and management of watershed microbial contaminants[J]. Critical Reviews in Environmental Science and Technology，2004，34( 2)：109-139
[5] 杨勇，魏源送，郑祥，等. 北京温榆河流域微生物污染调查研究[J]. 环境科学学报，2012,32(1)9-18
[6] Poté J，Goldscheider N，Haller L，et al. Origin and spatial—temporal distribution of faecal bacteria in a bay of Lake Geneva，Switzerland[J]. Environ Monit Assess，2009,154:337—348.
[7] EdwardALaws.水污染导论〔M〕.余刚，张祖麟.译.北京：科学出版社，2004：175.
[8] 中华人民共和国建设部.CJ3020—1993生活饮用水水源水质标准[S].1993.
[9] USEPA United States Environmental protection Agency. EPA440/5-86-001. QUALITY CRITERIA for WATER[S].1986
[10] Raina M.Maier，Lan L.PePper，carlesP.Gerba.环境微生物学[M].张甲耀，宋碧，郑连爽，等.译.北京：科学出版社，2004:598-674.
[11] 胡春华，黄丹，周文斌，等.典型湖泊边缘区丰水期营养状态及其影响因子研究—以蚌湖为例[J]. 水生态学杂志，2013,34（3）32-38
Seasonal Variation characteristics of microbial contamination in Poyang Lake Natural Reserve Waters

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Abstract: In order to understand characteristics of microbial contamination and water use function in Poyang Lake Natural Reserve (Poyang Lake Migratory Bird Sanctuary), Bang Lake, Da huchi, Sha Lake, Gan River and Xiu River were selected as research object. Samples were set in Bang Lake, Sha Lake and so on in different level seasons. Three sampling sections were set about Bang Lake by the direction of flow in wet season, level season and dry season in 2012-2013. Four kinds of indictor bacteria including the total number of colonies, total coliforms, fecal coliforms and enterococcus, three kinds of pathogenic bacteria including salmonella, golden staphylococcus and hayes bacteria were tested and analyzed. The results showed that: (1) The pollution levels of five waters: Bang Lake > Sha Lake > Da huchi Lake > Xiu River > Gan River. Faecal pollution mainly came from the human being. The detecton rate of pathogenic bacteria: Bang Lake > Sha lake > Da huchi > Gan River = Xiu River. (2) The total number of colonies in Bang Lake: wet season < level season < dry season. Various seasons were polluted by faecal, faecal pollution mainly came from the human being in wet season and level season, however faecal pollution mainly came from the animal in dry season. The water quality of three seasons were not conform to requirements of drinking water and recreational water, different degree of pathogenic bacteria were detected in three seasons. (3) The differences among the total number of colonies (logarithm 2.77±0.17 ～ 4.38±0.62), total coliforms (logarithm 3.51±0.19 ～ 4.77±0.31),and enterococcus (logarithm 2.77±0.22 ～ 4.00) were statistically significance (P<0.05),except fecal coliforms (The numerical 2.91±0.37 ～ 3.49±0.52) was not statistically significance (P > 0.05).(4) The fecal coliforms level was not statistically significance with fecal coliforms and enterococcus, two other instructions bacteria were statistically significance and positively correlated.(5) The total number of colonies, enterococcus were statistically and positively correlated with three pathogenic bacteria (P<0.05). The total coliforms had a good indication for the role of Salmonella.

Keywords: Poyang Lake Migratory Bird Sanctuary; Bang lake; Microbiological indicator; Correlation
鄱阳湖受损湿地土壤环境因素的空间分布研究

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摘 要：湿地土壤是湿地生态系统的重要组成，受损湿地生态系统的恢复以土壤修复为基础。本文通过野外典型土壤取样，分析鄱阳湖受损湿地土壤理化属性，揭示鄱阳湖沼泽土、草甸土 A、草甸土 B、水稻土、草甸沼泽土等 5 类受损湿地土壤属性的空间分布特征。研究结果表明，鄱阳湖湿地土壤均呈强酸性，阳离子交换能力偏低，土壤缓冲性能较弱，有效养分贫瘠。天然沼泽湿地土壤有机质和全氮累积的趋势基本一致，表现为表层土壤有机质、全氮含量最高，随着深度的增加，土壤有机质和全氮积累逐渐减少。天然沼泽土壤硝态氮含量在土壤剖面层中具有明显的差异，受土壤质地和土壤水分的影响，硝态氮含量垂直向下运移速度不同，砂质土壤比淤土更易于硝态氮淋失。与硝态氮相比，铵态氮更容易被土壤吸附，其含量在土壤不同深度均高于硝态氮含量，但是土壤之间的铵态氮含量差异不大。采样点土壤均未受到重金属污染，土壤重金属多数集中于 20～40cm 剖面，且天然沼泽湿地土壤重金属来源均有同源性，以靠近鄱阳湖最近的沼泽土壤重金属含量最高。研究结果为受损湿地生态修复与重建选择合适的技术模式提供参考依据。

关键词：受损湿地土壤；空间分布；土壤重金属；鄱阳湖

湿地土壤是湿地生态系统的一个重要组成部分，具有维持生物多样性、分配和调节地表水分、过滤、缓冲、分解固定和降解有机物和无机物、维持历史文化遗迹等功能。它是湿地获取化学物质的最初场所，也是湿地发生化学变化的介质[1]。与陆地土壤和水成土壤相比，湿地土壤具有其特殊性，在湿地特殊的水文条件和植被条件下，湿地土壤有着自身独特的形成和发育过程，表现出不同于一般陆地土壤的特殊的理化性质和生态功能[2]。这些性质和功能对于湿地生态系统的维持和演变具有重要作用。近年来，全球湿地出现了不同程度的退化，湿地的环境问题日益突出，湿地生态恢复已经成为 21 世纪国际湿地科学研究的热点与前沿之一[3-5]。伴随着湿地生态系统功能的改变，湿地的土壤类型在不断变化着，以土壤为载体的植被群落也发生了变化，因此湿地土壤恢复已成为湿地生态恢复重要组成部分[6]。研究湿地土壤环境质量的空间分布，剖析湿地土壤生态功能的变化规律是湿地生态恢复的基础性工作。

鄱阳湖是我国最大的淡水湖，鄱阳湖湿地是国际重要湿地之一，目前鄱阳湖湿地正面临着生态功能逐渐退化的威胁。本研究以鄱阳湖受损湿地为研究对象，结合国家科技支撑计划《鄱阳湖湿地生态修复与重建》研究项目，通过野外采样分析了鄱阳湖湿地土壤环境变化特征，旨在为受损湿地生态修复与重建选择合适的技术模式提供参考依据。
1 材料和方法

1.1 研究区概况

研究区选在隶属鄱阳湖湿地的江西省都昌县多宝乡马家堰村（东经116°06′51″～116°07′7″，北纬29°21′15″～29°22′50″），高程9.37～20.7 m，面积约20 ha。地貌组合结构主要由枯水期支流河道两侧天然堤—侧缘缓坡—碟形洼地组成，属亚热带湿润季风性气候。研究区水位与鄱阳湖水位的年内变化趋势一致。湿地从空间分布上看可分为开阔水域、季节性淹没带和渍水沼泽，分布在鄱阳湖湿地生态系统中具有典型性特征。受鄱阳湖水位的影响，最高水位为1998年8月2日的22.43 m，最低水位为2008年1月17日的8.05 m，多年来平均水位为13.86 m。目前开阔水域已被承包用于水产养殖，其他大部分是由草洲和滩地取代的湿地，其植被景观与功能有很大的变化。按照高程划分，研究区湿地土壤类型主要以沼泽土、草甸土、水稻土、草甸沼泽土为主。其优势作物为湖漫滩草甸主要，受到人为活动和放牧影响，草甸现有生物量低下，水生植被缺乏，退化严重。湖漫滩以泥滩地为主，湿地植被发育不良。

1.2 设计处理与样品采集

为了研究不同湿地植被对湿地土壤环境的变化特征，分别在沼泽土、草甸土 A、草甸土 B、水稻土、草甸沼泽土等典型地带选取 5 块 0.5 ha 大小的区域作为研究样地（表 1）。每个研究样地设置 5 个采样点，随机排列，按照 0～20 cm（表层土）、20～40 cm（中层土）、40～60 cm（深层土）3 个土壤剖面采集，同时标记采样点地理位置。样品采集使用自制沉积物采样器，每个研究样地按照对应的土壤剖面采集，然后混合成 1 份土壤样品。因草甸土 B 和草甸沼泽土 20 cm 以下均为泥水，未取深层土壤层样本，5 个研究样地共采集土壤样品 13 份，用来分析土壤基本特性及空间垂直变化。

| 区域 | 土壤类型 | 高程(m) | 环境特征 |
|------|----------|--------|----------|
| 1    | 沼泽土   | 12.4～13.5 | 土壤长期遭水淹，仅冬季枯水期出露。土壤表面积有零星稀疏植被，表层为淤泥，潮湿，母质层厚度 40 cm，40 cm 以下为泥沙。距鄱阳湖水面约 500 m 左右。 |
| 2    | 草甸土 A  | 15.7～16.2 | 土壤仅汛期（每年 6～9 月）淹没，淹水期较短，有草本植物覆盖，如_BUSY_A_草，黄花草，红花草，苔草等。土壤母质层厚度超过 100 cm，100 cm 以下未见泥沙。土壤质地较软，比较坚硬。 |
| 3    | 水稻土   | 14.8～14.9 | 土壤有植被覆盖，遭遇淹水。原先为水稻田，有秆子草等。 |
| 4    | 草甸土 B  | 18.10～18.50 | 沙土，表层土壤有沙，土壤质地干燥，仅洪水期淹没。土壤母质层厚度 25 cm，25 cm 以下均见沙。 |
| 5    | 草甸沼泽土 | 15.0～15.5 | 表层土壤上覆盖枯草，有沙，15 cm 以下含沙较多。土壤母质层厚度 25 cm，25 cm 以下为含水沙层。 |
1.3 分析项目与分析方法

土壤 pH 用土壤 pH 测定仪; 有机质用重铬酸钾容量法; 全氮用半微量凯氏定氮法; 全磷用 NAOH 熔融一钼锑抗比色法; 有效磷用 0.05mol·L⁻¹ HCl—0.025mol·L⁻¹ (1/2H₂SO₄) 法; 全钾用等离子体光谱仪; 速效钾用原位吸收光谱仪发射法; 氮化钠用离子色谱法; 速效磷用 0.05mol·L⁻¹ HCl—0.025mol·L⁻¹ (1/2H₂SO₄) 法; 总铜、总锌、总铅、总汞用原子吸收分光光度法; 总砷用二乙基二硫代氨基甲酸银分光光度计。

2 结果与分析

2.1 土壤 pH 和阳离子交换量(CEC) 的空间变化

图 1 可以看出, 整个剖面 (0~60 cm) 层土壤 pH 值均在 5.6 以下, 土壤表现强酸性。中层土壤剖面, 除草甸土 A 的土壤酸性表现为随土壤深度增加而增强以外, 其余 4 种类型土壤 pH 空间分布均表现出一致的变化规律: 表层土壤酸性最强, 随着深度的增加至 20~40 cm, 酸性变弱, 沼泽土和水稻土在 40~60 cm 土壤层酸性再度加强。

表层土壤酸性表现为草甸土 B > 草甸沼泽土 > 水稻土 > 沼泽土 > 草甸土 A, 而中层为草甸沼泽土 > 草甸土 B > 草甸土 A > 水稻土 > 沼泽土。表层土壤草甸土 A 的酸性表现最弱, 是由于该处土壤只在汛期 (每年 6-9 月) 遭到大水淹没, 淹水期较短, 土壤表面长期有不同草本植物覆盖。中层沼泽土酸性表表现最弱, 是因为该处土壤母质为近代河湖沉积物, 处于洪水期水位波动带, 表层土壤稀疏, 土壤长期处于淹水状态, 是在生长喜湿植物的条件下形成的。

土壤 pH 是土壤的一个基本性质, 也是影响土壤理化性质的一个重要化学指标, 它直接影响着土壤中各种元素的存在形态、有效性和迁移转化。土壤 pH 值包括土壤活性酸度和潜在酸度, 其潜在酸度与阳离子交换量 (又称土壤缓冲能力) 有关。由图 2 可知, 土壤 CEC 均在 12~13 Cmol (+) ·kg⁻¹ 之间, 说明土壤腐殖质含量偏低, 土壤缓冲性能较差。5 种不同类型的湿地土壤, 其表层 CEC 大小为草甸土 A > 水稻土 > 草甸土 B > 草甸沼泽土 > 沼泽土, 缓冲性能以草甸土 A 为强, 而以沼泽土缓冲性能最差。表层土壤 CEC 为草甸土 A > 草甸土 B > 水稻土 > 草甸沼泽土 > 沼泽土, 深层为草甸土 A > 沼泽土 > 水稻土。

图 1 土壤 pH 的空间分布
图 2 土壤阳离子交换量 (CEC) 的空间分布
2.2 土壤养分空间变化

2.2.1 土壤有机质(SOM)、全氮(TN)空间分布

由图3可知，各种土壤不同剖面SOM含量存在差异，表层土壤SOM含量为7.15～20.00 g•kg⁻¹，中层为1.14～8.22 g•kg⁻¹，深层为0.50～6.22 g•kg⁻¹。SOM积累的趋势基本一致，表层SOM含量最高，随着深度的增加，SOM积累逐渐减少。表层土壤是植物根系及植物残体的集中分布区，大量死亡的根系和植物残体在低温、潮湿的条件下腐解归还土壤，为土壤提供了丰富的碳源，加之地表枯落物也成为表层SOM积累的重要碳源。随着土壤深度的增加，植物的根系及残体难以进入土壤，分布较少，根系的周转量急剧下降，导致SOM积累相对减少。植物根系的分布直接影响土壤中SOM的垂直分布，与Jobbagy G、刘景双等研究结果相一致[9,10]。此外，由于土壤剖面不同深度水热状况不同，土壤SOM矿质化程度也不尽相同，造成土壤SOM垂直分布差异。

由于受到土壤母质发育程度、水文特征、外界干扰程度差异的影响，不同土壤类型同一层次SOM含量表现出明显的变异性特征。由图3可知，表层土壤SOM含量表现为草甸沼泽土>草甸土B>水稻土>沼泽土>草甸土A，而中层土壤表现为水稻土>沼泽土>草甸土A>草甸沼泽土>草甸土B，深层土壤为水稻土>草甸土A>沼泽土。表层土壤中，草甸沼泽土长期处于季节性积水、地下水位较高的地段，SOM腐殖化过程强烈，积累较多。而草甸土疏松多孔，通透性良好，水热状况较好，尽管生物量较高，但SOM矿质化过程显著加强，致使SOM积累相对减少。水稻土由于以前是人为长期水耕熟化的产物，土壤结构良好，水热状况好，加之水稻收获即被移走，导致土壤有机质积累减少。而沼泽土地表覆盖物较少，SOM含量偏低。而草甸土A土壤质地坚硬，土壤干燥，SOM含量最低，与前人研究结果基本一致[11,12]。

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由图4可知，除水稻土外，其余各种土壤TN含量分布均集中于土壤剖面的上层，由表向下呈下降趋势，差异显著，与SOM消长趋势类似。其中，受天然湿地对N素的滞留作用所致，沼泽土、草甸土A、草甸土B，草甸沼泽土表层土壤TN含量占剖面TN含量的55.3%、54.5%、56.8%、84.8%。由于水稻土是人为熟化的土壤，耕作层疏松，受淋溶作用，TN含量集中土壤剖面中层。

5种类型的土壤中，草甸土A、草甸土B和草甸沼泽土TN消长趋势一致，表层土壤TN含量为草甸土A最高，为0.42 g•kg⁻¹，其余差异不大。中层TN含量范围从0.05～0.46 g•kg⁻¹，差异显著。天然沼泽湿地土壤对N素的滞留机制主要是沉积作用和植物吸收，但是不同植被类型的湿地土壤对N素的吸收滞留能力不同，草甸土A由于地上生物量多，对N的吸收能力更强，致使表层土壤TN含量最高，而其余天然沼泽湿地土壤地下水位高，处于季节性积水状态，受到土壤硝化作用以及水流的冲刷作用，导致氮素淋失[13]。
2.2.2 土壤硝态氮 (NO\textsubscript{3}−-N)、铵态氮 (NH\textsubscript{4}+-N) 空间分布

由图 5 可知，受水分条件、土壤物理性质的影响，不同的沼泽土壤 NO\textsubscript{3}−-N 垂直淋洗的程度不一样。沼泽土表层与深层土壤 NO\textsubscript{3}−-N 浓度差异不大，土壤长期受水淹是导致土壤 NO\textsubscript{3}−-N 的垂直淋失量低的缘故。但表层与深层土壤 NO\textsubscript{3}−-N 含量均高于中层土壤，这说明地下水位的波动是导致沼泽土 NO\textsubscript{3}−-N 运移规律差异的重要原因 [14, 15]。

与沼泽土相比，草甸土 A 土壤 NO\textsubscript{3}−-N 含量垂直向下运移速度不同，明显高于沼泽土。表层土壤 NO\textsubscript{3}−-N 浓度显著高于中层土壤和深层土壤。这是因为草甸土 A 淹水期较短，土壤各剖面层 NO\textsubscript{3}−-N 含量及淋洗速度主要受到土壤物理性质的影响，土壤质地干燥，地下水位低，NO\textsubscript{3}−-N 含量的淋失速度加快。说明土壤物理性质是影响 NO\textsubscript{3}−-N 含量的淋洗速度的重要原因 [16]。水稻土土壤 NO\textsubscript{3}−-N 浓度垂直向下迁移规律刚好与前者相反，其深层土壤 NO\textsubscript{3}−-N 浓度要高于表层和中层土壤。草甸土 B 与之规律相似。受土壤物理性质的影响草甸沼泽土 NO\textsubscript{3}−-N 垂直迁移与草甸沼泽土类似。

同一层次不同土壤 NO\textsubscript{3}−-N 含量表现出明显的差异。表层土为沼泽土 > 草甸沼泽土 > 草甸土 A > 草甸土 B > 水稻土，其中沼泽土、草甸土 A、草甸土 B 无显著差异，与这三种土壤相比，草甸土和水稻土差异显著。

由图 6 可知，各种类型表层土壤 NH\textsubscript{4}+-N 含量为 30~70 mg•kg\textsuperscript{−1}，以草甸沼泽土含量最高，水稻土含量最低。中层土壤 NH\textsubscript{4}+-N 含量为 40~50 mg•kg\textsuperscript{−1}，无显著差异，但远远高于 NO\textsubscript{3}−-N 含量，说明土壤对 NH\textsubscript{4}+-N 的吸附能力很强。草甸土由于土壤质地干燥，地下水位低，因此各土壤剖面 NH\textsubscript{4}+-N 含量一致，而其余中层或深层土壤更多或少处于淹水状态，导致 NH\textsubscript{4}+-N 借助于渗透的驱动随水迁移，但由于其土壤水分、水位条件的不同，导致其随土壤深度的增加而表现出不同的规律。水稻土 NH\textsubscript{4}+-N 在土壤剖面中分布随土壤深度增加而增加，草甸土因其长期处于干燥状态而对 NH\textsubscript{4}+-N 的变化影响不大，其余三种土壤 NH\textsubscript{4}+-N 均表现为随深度增加而降低。与 NO\textsubscript{3}−-N 相比，NH\textsubscript{4}+-N 更容易被土壤吸附，在自然干燥的土壤
中 NO$_3$-N 在土壤剖面层中具有明显的差异，但是对 NH$_4$-N 的影响并不大，它只有在特定条件下如土壤水分接近饱和的情况下借助于下渗流的驱动下才可能在土壤剖面中随水迁移。

硝态氮(mg/kg)  
0 1 2 3 4 5 6  
土壤深度(cm) 
沼泽土 草甸土A 水稻土 草甸土B 草甸沼泽土

铵 态氮(mg/kg)  
20 30 40 50 60 70 80  
土壤深度(cm) 
沼泽土 草甸土A 水稻土 草甸土B 草甸沼泽土

2.2.3 土壤有效养分磷（AP）、钾（AK）空间分布

钾是植物所必需的大量元素，由图 7 可知，沼泽土剖面以中层土壤 AK 含量最高，为 73.4 mg•kg$^{-1}$，表层土壤次之（69.5 mg•kg$^{-1}$），其次为深层土壤（44.3 mg•kg$^{-1}$）。草甸土 A 剖面含量分别为 51.9 mg•kg$^{-1}$、50.7 mg•kg$^{-1}$、57.1 mg•kg$^{-1}$，变化不大。水稻土 AK 含量随着土壤深度的增加而增加。草甸土 B 和草甸沼泽土土壤剖面 AK 变化趋势基本类似，均随着土壤深度的增加而减少，分层变异明显。

同一层次各种不同表层土壤均表现为沼泽土＞草甸土 B＞水稻土＞草甸沼泽土＞草甸土 A，无显著差异；中层土壤为沼泽土＞水稻土＞草甸土 A＞草甸土 B＞草甸沼泽土，差异显著；深层土壤以水稻土为最高，达 94.5 mg•kg$^{-1}$。纵观 AK 含量，发现所有土壤 AK 含量均处于极低水平，钾供应严重不足。

由图 8 可知，沼泽土土壤剖面其 AP 含量以中层土壤为最高（6.27 mg•kg$^{-1}$），表层土壤次之（4.02 mg•kg$^{-1}$），深层土壤最低（0.98 mg•kg$^{-1}$），差异显著。其余土壤 AP 含量随深度的增加而增加，变化不大。这是因为受鄱阳湖水的冲洗作用，或磷地质浸积作用，而使最高有效磷含量没有出现在表层土壤中。除水稻土外，其余均表现为深层土壤小于中层土壤，可能是深度的增加，土壤呈现缺氧或者厌氧状态，土壤吸附磷能力减弱。尤其是沼泽土完全处于厌氧状态，导致土壤吸附能力减弱。

各种类型的土壤在表层和中层剖面同一层次 AP 含量均为沼泽土＞草甸土 A＞水稻土＞草甸沼泽土＞草甸土 B。因为沼泽土长期处于淹水状态，偶尔在冬季出露，其地上凋落物易
分解，导致沼泽土高于其他4种土壤。而其余4种土壤地上植被生产力大，土壤微生物对磷的吸附作用大于积累作用，植被不易分解被吸附，导致土壤有效磷含量小于沼泽土采样点。
表 2 土壤重金属含量 单位: mg•kg⁻¹

| 土壤重金属 | 采样深度 cm | 沼泽土 | 草甸土 A | 水稻土 | 草甸土 B | 草甸沼泽土 |
|------------|-------------|--------|-----------|--------|----------|------------|
|             | 0~20        | 17.6   | 7.72      | 13.4   | 5.19     | 1.32       |
| 铜          | 20~40       | 19.9   | 10.2      | 14.8   | <0.3     | <0.3       |
|             | 40~60       | 3.18   | 10.5      | 16.2   |          |            |
|             | 0~20        | 46.5   | 26.2      | 36.6   | 10.2     | 16.0       |
| 锌          | 20~40       | 52.4   | 32.0      | 48.3   | 6.99     | 7.65       |
|             | 40~60       | 6.38   | 26.0      | 47.2   |          |            |
|             | 0~20        | 21.4   | 11.0      | 18.2   | 9.58     | 6.81       |
| 铅          | 20~40       | 26.9   | 12.6      | 21.2   | 2.66     | 4.52       |
|             | 40~60       | 2.70   | 14.6      | 24.2   |          |            |
|             | 0~20        | 0.03   | 0.02      | 0.04   | 0.03     | 0.04       |
| 汞          | 20~40       | 0.02   | 0.04      | 0.05   | 0.02     | 0.01       |
|             | 40~60       | <9×10⁻⁴| 0.03      | 0.05   |          |            |
|             | 0~20        | 5.10   | 4.32      | 4.70   | 2.40     | 1.40       |
| 砷          | 20~40       | 5.84   | 3.91      | 1.46   | 1.85     | 0.52       |
|             | 40~60       | 1.76   | 4.69      | 7.48   |          |            |

3 结论

（1）受损湿地土壤普遍呈强酸性，阳离子交换性能偏低，土壤缓冲性能较弱。不同土壤类型，表层土壤以草甸土 B 酸性最强，草甸沼泽土次之，中层土壤剖面以草甸沼泽土酸性最强，草甸土 B 次之，且土壤酸度越大，其湿地物种减少。阳离子交换性能偏低，土壤腐殖质较低，土壤缓冲性能下降。

（2）受到土壤母质发育程度、水文特征、外界干扰程度的差异的影响，不同土壤类型同一层次土壤有机质含量表现出明显的变异特征，表现为表层土壤以草甸沼泽土为最高，20~60cm 层以水稻土最高。不同类型土壤有机质积累趋势基本一致，表现为表层土壤有机质含量最高，随着深度的增加，土壤有机质积累逐渐减少。

（3）除水稻土全氮含量集中于土壤中层，其余各种土壤全氮含量分布均集中于土壤表层，由表向下呈下降趋势，差异显著。土壤有机质含量受地表植被覆盖、水热条件影响等影响，导致各类型湿地土壤有机质含量具有明显的差异。天然沼泽土壤全氮消长趋势一致。天然沼泽土壤主要受土壤水分和土壤物理性质的影响，导致土壤硝态氮含量垂直向下运移速度差异显著。由于土壤对铵态氮的吸附能力很强，导致各种类型土壤铵态氮含量远远高于土壤...
硝态氮含量，但无显著性差异。

（4）土壤速效钾、有效磷含量具有明显的差异，分布规律不同。速效钾含量处于极低水平，钾供应严重不足。受鄱阳湖水的冲洗作用，或磷地质沉积作用，而使最高有效磷含量没有出现在表层土壤中。

（5）与土壤环境质量一级标准相比，土壤重金属含量未超标，说明鄱阳湖湿地土壤均未受到重金属污染，生态环境质量良好。而沼泽土剖面，铜、锌、铅、砷重金属含量均为中层土壤含量为最高，且在同一层次高于其他类型土壤重金属含量，且沼泽土、草甸土、草甸沼泽土具有同源性，因此应该注意该类型土壤的重金属含量变化，如果处理不当，将会引起湿地水体的水环境发生变化，应注意保护，防止造成重金属污染。

（6）鄱阳湖湿地土壤酸化严重，缓冲性能、养分含量等低，供钾能力不足，土壤肥力贫瘠，这些与地上植被稀疏，物种数量少有关，植物修复对调整土壤 pH，养分含量分布有一定的作用，应注意根据不同的土壤类型，选择合适的植物对湿地进行生态修复。

参考文献：
[1] 姜明, 吕宪国, 杨青. 湿地土壤及其环境功能评价体系. 湿地科学, 2006, 4(3): 168-172
[2] 杨青, 刘吉平. 中国湿地土壤分类系统的初步探讨. 湿地科学, 2007, (2): 111-115
[3] Erwin KL, et al. Successful construction of a fresh water herbaceous marsh in South lorida. USA. In: Mitsch WJ ed. Global wetlands: old world and new. Elsevier, Netherlands, 1994
[4] 杨永兴. 从魁北克2000-世纪湿地大事件活动看21世纪国际湿地科学研究的热点与前沿. 地理科学, 2002, 22(2): 150-155
[5] 左平, 宋长春, 钦佩. 从第七届国际湿地会议看全球湿地研究热点及进展. 湿地科学, 2005, 3(1): 66-73
[6] 黄树辉, 吕军. 裂缝对稻田土壤溶液中氮运移的影响. 农业环境科学学报, 2004, 23(3): 499-502
Study of Space Distribution on Environmental Factors in Damaged Wetland Soils of Poyang Lake

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Abstract: Soil is a key component of wetland ecosystem, and remediation is the basis for restoration of damaged wetland ecosystems. This study studied the chemical and physical aspects of damaged wetland soil in Poyang Lake, and revealed their spatial distribution features of five different damaged wetland soil types. The damaged soil types included a boggy soil, two meadow soils, a paddy soil and a meadow-boggy soil. The result showed that the damaged wetland soils have low soil pH and cation exchange capacity (CEC), and soil nutrients were in the impoverished state. There was a similar spatial distribution character between soil organic matter (SOM) and total nitrogen (TN) in 5 types of soils. The accumulation of SOM and TN showed the same tendency: the concentrations of SOM were the highest in the surface layer, but declined in the deeper levels. Soil texture and soil moisture significantly affected the spatial distribution of N. Due to higher vertical traveling speed of NO$$_3$$-N in soil, sandy soil was more easily leaching than sludge soil. On the other hand, the concentrations of NH$$_4$$+N in different soil layers were significantly higher than the content of soil NO$$_3$$-N in the counterparts, indicating soil has strong adsorption ability for NH$$_4$$+N. However, soil NH$$_4$$+N content of different soil types in the same layer had no significantly differences. The result also showed that the heavy metals gathered in the middle layer (20 ~ 40 cm) and resulted from the same source. The heavy metal content of boggy soil near Poyang lake were the highest in all five types of soils. In addition, the heavy metals level in sampling site, including Zn, Cu, Pb, Hg, As, were lower than those in soil environmental quality standard. The results could provide the reference for damaged wetland ecological restoration and reconstruction choosing the appropriate technology model.

Keywords: Damaged wetland soil; Space distribution; Soil physical and chemical factors; Poyang lake
鄱阳湖水质动态监控及其生态保护对策研究

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摘要：对近十年（2004～2013年）鄱阳湖水质动态监控状况及其水生态情况进行研究，结果表明鄱阳湖水质总体呈下降趋势，目前富营养化状况属中营养状态，主要污染物为总磷、氨氮。运用季节性Kendall检验法对主要污染物总磷、氨氮进行变化趋势分析，湖区大部分监测断面、湖口控制断面总磷、氨氮呈显著上升趋势。鄱阳湖在水华风险评估上总体是安全的，藻细胞密度无明显升降趋势。针对鄱阳湖水质和水生态现状，提出了鄱阳湖水环境、水生态保护对策。

关键词：鄱阳湖；水质；水生态；藻类；保护

1 前言

鄱阳湖为我国第一大淡水湖，它位于江西省的北部、长江中下游南岸，承纳赣江、抚河、信江、饶河、修河等“五河”及博阳河等支流来水，经调蓄后由湖口注入长江，属型季节性淡水湖泊。鄱阳湖不仅是长江洪水和五河洪水重要的调蓄场所，也是世界著名的湿地，在我国乃至全球生态格局中占有十分重要的地位[1]。进入21世纪以后，江西省加快推进工业化、农业化和城镇化进程，（环）鄱阳湖区域的人口、资源、环境面临更大的压力。近年来受干旱气候和其他因素的严重影响，鄱阳湖水情态势发生较大变化（如枯水位提前等），易造成生态环境严重衰退，湿地功能退化、土地严重沙化等现象将日益凸显[2]。因此加强鄱阳湖水质动态监测，建立水生态安全监测体系，及时掌握湖泊水生态变化，健全相关的保护措施，是保障鄱阳湖水环境与水生态安全的关键所在。

2 近十年来鄱阳湖水质动态监控状况及其水生态情况分析

按照《地表水环境质量评价办法》，对2004～2013年鄱阳湖水环境质量进行评价，结果显示鄱阳湖水质总体呈下降趋势。2004～2007年间，长江上游来水减少，省内降雨偏少，湖区低水位下降，该期间江西经济发展迅速，工业化加快，废污水排放量增加，水质下降急剧；2008～2013年间，长江上游来水增多，省内降雨偏多，湖区水位上升，该期间社会经济保持可持续发展，对污水排放进行有效控制，水质状况有所好转。
其中，2004～2013年间全年水质优于或符合Ⅲ类水的占15.0～91.1%，平均64.9%；汛期水质优于或符合Ⅲ类水的占24.0～99.6%，平均76.4%；非汛期水质优于或符合Ⅲ类水的占8.7～85.1%，平均46.6%。4～9月富营养化评价值为44～49，属中营养。主要污染物为总磷、氨氮，污染的重点区域分布于东部湖域的乐安河口、信江东支口、鄱阳，主湖区的龙口、瓢山、康山，南部湖域的信江西支口等水域。如图1所示，从整体来看汛期水质好于全年，非汛期水质最差，总体呈下降趋势，Ⅰ～Ⅲ类水比例由2004年的91.1%下降至2013年的64.2%。其中2007年和2011年出现明显的水质下降过程。

通过对鄱阳湖主要污染物总磷、氨氮，对湖体各水域进行比对分析，如图2、图3所示，发现鄱阳湖总体总磷、氨氮浓度均呈明显上升趋势。全湖总磷浓度2008年之后都较往年有明显的增加趋势，其中东部湖域增加幅度更为显著，东部乐安河入湖控制站总磷浓度同期也出现了跳跃性增长。现阶段从水域来看，东部湖域的总磷浓度最大，其次为南部湖域，2008～2013年总磷浓度增加较为明显的也在这两处水域。2013年湖区总磷最大值位于东部湖域的乐安河口断面，其次为东部湖域的鄱阳断面。东部湖域总磷增大，主要可能受乐安河企业扩张的影响；南部湖域总磷增大，主要可能受渔业发展、饲料和化肥投放增加的影响。北部湖域现状总磷浓度最小，整体变化趋势也相对较为平缓，2013年湖区总磷最小值位于北部湖域的修河口断面。

通过运用季节性Kendall检验法对总磷参数进行变化趋势分析，18个湖区监测断面中，乐安河口等9处断面总磷呈高度显著上升趋势，昌江口等6处断面总磷呈显著上升趋势，康山等3处断面总磷无明显升降趋势。鄱阳湖出湖控制断面湖口，总磷呈高度显著上升趋势。
湖区氨氮变化情况与总磷情况类似，也呈明显的上升趋势，东部湖域氨氮浓度增大最为典型。东部湖域氨氮浓度值较的乐安河口断面，与其上游乐安河入湖控制水文站，2008年后氨氮浓度都出现了明显的同步跃性增长。现阶段从区域来看，东部湖域的氨氮浓度值最大，其次为南部湖域。2013年湖区氨氮最大值位于东部湖域的乐安河口断面，其次为东部湖域的鄱阳断面。北部湖域现状氨氮浓度最小，2013年湖区氨氮最小值位于北部湖域的修河口断面。季节性 Kendall 检验法氨氮变化趋势分析成果也显示：鄱阳等 11 处断面氨氮呈高度显著上升趋势，乐安河口等 3 处断氨氮呈显著上升趋势，昌江口等 3 处断氨氮无明显升降趋势。鄱阳湖出湖控制断面湖口，氨氮呈显著上升趋势。
表 1 鄱阳湖 2009～2013 年藻类监测情况

| 断面名称 | 藻细胞密度（10^4ind/L） | 多年平均值（10^4ind/L） | 优势种 | 所属门 |
|-------|----------------|----------------|--------|--------|
| 蚌湖  | 47.6～1760.0  | 395.5 | 微囊藻 | 蓝藻  |
| 都昌  | 37.3～1287.0  | 240.9 | 微囊藻 | 蓝藻  |
| 湖口  | 17.0～328.4   | 110.8 | 直链藻 | 硅藻  |
| 康山  | 36.0～1452.0  | 211.8 | 直链藻 | 硅藻  |
| 蛇山  | 22.8～562.8   | 166.2 | 直链藻 | 硅藻  |
| 星子  | 1.1～335.3    | 115.8 | 直链藻 | 硅藻  |

在水环境问题中，富营养化是当今最受关注的课题之一。水体富营养化主要是天然水体接纳过量的营养物质，如氮、磷，使藻类以及其他水生生物异常繁殖，造成水质恶化，使水生态系统和水体功能受到影响和破坏。20 世纪以来，在亚太地区有 54% 的湖泊呈富营养化状况，而欧洲、北美洲、非洲和南美洲的湖泊富营养化比例分别为 53%、28%、48% 和 41%[4-6]。藻类的连续监测成为水体富营养化研究和监控的关键手段。

自 2009 年开始，江西省水文局对鄱阳湖蚌湖、都昌、湖口、康山、蛇山、星子等 6 处断面开展藻类监测（部分研究结果表 1）。连续 5 年的监测结果表明：鄱阳湖在水文风险评估上总体是安全的，鄱阳湖藻细胞密度范围为 1.1 万～1760 万个/L，均值为 210.9 万个/L。藻细胞密度最小值发生于 2011 年 4 月的入江水道区星子断面，最大值发生于 2011 年 12 月的北部湖域蚌湖断面。运用季节性 Kendall 检验法，对上述 6 处断面藻细胞密度进行变化趋势分析，均无明显升降趋势。丰水期优势藻为蓝藻门，以微囊藻为主；枯水期优势藻为硅藻门，以直链藻为主。从各断面来看，北部湖域蚌湖断面多年平均藻细胞密度最大，为 395.5 万个/L，其次为北部湖域都昌断面，多年平均藻细胞密度为 240.9 万个/L，这两处断面水域的藻类优势种均为蓝藻门的微囊藻。出湖控制断面湖口多年平均藻细胞密度最小，为 110.8 万个/L。主湖区康山、北部湖域蛇山、入江水道区星子、出湖湖口等 4 处断面水域的藻类优势种均为硅藻门的直链藻。

3 保护对策

从上述研究结果来看，目前鄱阳湖的水质及水生态情况尚属良好，是全国淡水湖泊中水环境质量最好的湖泊之一，但受工业化和城市化进程加快的影响将会发生恶化趋势。为保护鄱阳湖“一湖清水”，结合江西省省情和水文现状，提出以下几点水环境、水生态保护对策：

（1）健全相关保护措施，对主要入湖河道（“五河”）实施水污染情况动态实时监控。根据“五河”流域的社会经济状况和水污染特点以及对鄱阳湖水环境的影响，首先应重点加强“五河”流域生活、工业污染源和农村面源污染控制；其次污水处理厂选址应按污水汇流集中到各污染源产生点距离最小的原则优化选择，既可以减少污水管道建设，又能保证处理
后中的水就近利用。各河流区域还应建立或健全相关的保护措施和制度。

（2）加强城镇污染的集中控制，加快城镇污水处理厂建设进程，完善污水收集管网，提高污水处理效率和处理深度。将工业污染源达标成果，加强管理，杜绝偷排现象发生，提高工业废水集中处理水平。此外，还应开展鄱阳湖全流域产业结构调整，实施清洁生产，坚持总量控制管理，最终减少污染物入湖总量。

（3）加强对鄱阳湖湖滨区畜牧业污染源的控制，对畜牧业产生的废水采取合适的污水处理措施，保证污水的处理效果或保证废水不外排。加强对家禽养殖场的管理，推行对家禽粪便、废饲料的综合利用。

（4）优化水产养殖模式，减少人工投加饵料带来的影响或将其养殖废水纳入废水处理的范围。根据鄱阳湖当地的蟹、虾、蚌与经济鱼类的生态生理特征，将水产健康养殖和污染生态控制技术有效集成，进行合理的轮养，套养，以减少水产养殖污染，提高养殖经济效益，达到更好的水生态修复效果，走可持续健康的水产养殖道路。

4 结论

对2004～2013年鄱阳湖水质动态监控状况及其水生态情况研究表明，近年来鄱阳湖水质总体呈下降趋势，目前富营养化状况属中营养状态，主要污染物为总磷、氨氮，污染的重点区域分布于东部湖域、南部湖域。

运用季节性 Kendall 检验法对主要污染物总磷、氨氮进行变化趋势分析，18个湖区监测断面中，有9处断面总磷呈高度显著上升趋势，6处断面呈显著上升趋势。11处断面氨氮呈高度显著上升趋势，3处断面呈显著上升趋势。鄱阳湖出湖控制断面湖口，总磷呈高度显著上升趋势，氨氮呈显著上升趋势。

鄱阳湖在水华风险评估上总体是安全的，对2009年～2013年湖区6处断面的藻类监测成果进行分析，藻细胞密度无明显升降趋势。丰水期优势藻为蓝藻门，以微囊藻为主；枯水期优势藻为硅藻门，以直链藻为主。

为保护鄱阳湖“一湖清水”，从控制入湖污染源，加强城镇污染集中控制，提高污水处理效率和处理深度，加强对鄱阳湖湖滨区畜牧业污染源的控制，优化水产养殖模式等方面提出了鄱阳湖水环境、水生态保护对策。

参考文献

[1] 鄱阳湖研究编委会. 鄱阳湖研究[M]. 上海：上海科技出版社，1988.
[2] 黄国勤．保护鄱阳湖“一湖清水”的重大意义及战略对策[J]. 中国人口·资源与环境, 2011, 21: 281-285.
[3] 姜霞, 郑朔方, 储昭升. “湖泊富营养化综合治理”, 中国生物产业发展报告[M]. 北京：化学工业出版社, 2008: 230-244.
[4] 谢钦铭, 李长春, 彭赐莲. 鄱阳湖浮游藻类群落生态的初步研究[J]. 江西科学, 2000, 18 (3): 162~166.
[5] Smith VH, Eutrophication of freshwater and coastal marine ecosystems: A global problem. Environ. Sci. Pollut. Res., 2003, 10 : 126-39.
[6] Chorus I, Bartram J, Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management. London: E&FN Spon, 1999, pp. 41-111.
Water Quality Dynamic Monitoring and Ecological Protection for Poyang Lake

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Abstract: The water quality dynamic monitoring and water ecosystem for Poyang lake during the nearly 10 years (2004~2013) were studied in this paper. The results showed that the water quality in general presented a decreasing trend, the current eutrophication status was moderate, and the main pollutants were the total phosphorus (TP) and ammonia nitrogen (NH$_3$-N). By using the seasonal Kendall test for the main pollutants of TP and NH$_3$-N, it was found that TP and NH$_3$-N appeared a significantly rising trend for most of monitoring cross-sections in the lake and the controlling-sections in the lake outlet. From the results of water bloom evaluation, it was still safe for Poyang lake and the algal density has no obvious variation trend. Moreover, some protection countermeasures were proposed according to current situation of water quality and water ecosystem in Poyang lake.

Keywords: Poyang Lake; Water quality; Water ecosystem; Algae; Protection
生态浮床—一种原位生态修复技术简介

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摘 要: 生态浮床技术是一项重要的原位修复人工湿地技术，与其他修复技术相比，具有不占有土地，原位修复，环境友好的特点，在国内外相关研究中已经被证明具有良好的应用价值。

本文从生态浮床的原理, 生态浮床的分类, 应用原则及国内外研究方面对生态浮床做简介, 期望通过本文能够让更多的人认识并认同生态浮床技术。

关键词: 生态浮床，原位修复

引言

生物浮床（Ecology Floating-beds System）是一项重要的人工湿地技术，自从上世纪80年代在德国被发明并投入使用以来，生物浮床技术因其在富营养化水体治理中独特的优势，脱颖而出，已经被越来越多的科学家及政府部门认可。生物浮床，也称“人工生物浮床” [1], “人工浮岛” [2,3], “浮床无土栽培” [4], 它运用无土栽培原理，把水生植物或改良的陆生植物以人工构建的浮床为载体，栽种到富营养化水体的表面，通过植物本身在生长过程中从水体中吸收氮、磷等营养物质的特点，除去水体中的氮、磷等营养元素；通过发达的根系，发挥对污染物的吸附降解作用；同时为微生物的生存及降解水体中的有机污染物提供必要的场所；同时还通过与藻类竞争养分、氧气起到抑制藻类生长的作用（图1-1）。已经广泛应用于包括农业废水处理，城市雨水处理，养殖废水，富营养湖泊治理等各个方面 [5-9]。它具有以下优点：(1) 它直接从水体中去除营养物，可以通过移除植物的方式把水中的营养物质从水中直接移除，对水体环境破坏小，是一种重要的水体修复和控制技术；(2) 它能够对废水进行原位修复，费用低廉，不占用额外的土地；(3) 生态浮床终端产品能够产生经济价值，容易被大众和地方政府接受；(4) 它不消耗能源，能够适应动态变化的水位；(5) 环境友好，能够为其它水生生物创造适宜的生存环境，同时还具有景观价值，体现了一种新型的水体生态管理和污染控制思路。
生态浮床主要分为干式浮床和湿式浮床。

所谓的干式浮床是指在浮床中生长的植物与治理的水面没有直接接触，对于水面污染的净化没有用处，主要是作为景观而栽培的。湿式浮床是与水面直接接触，对水质的净化效果较好。

湿式浮床又分为2大类，一类为用纤维强化塑料、混凝土、不锈钢加发泡聚苯乙烯、盐化乙烯合成树脂、特殊发泡聚苯乙烯加特殊合成树脂等材料制作而成的有框型湿式浮床；另一类为用椰子纤维编织而成的无框湿式浮床。目前所用的浮床还是湿式浮床为主。

按照不同的分类方法浮床又可以分为以下两类：传统式生态浮床和组合式人工生态浮床。

传统式生态浮床：传统式生态浮床一般是由3部分组成，浮床的整体框架、水下固定装置和水生植物。为了能够获得浮床单元设计的空间配置，浮床在水体中的固定是重要的，一般基本的固定方法有3种：重力型、杆定型和锚定型。框架采用最多的是硬聚氯乙烯（UPVC）管材和竹子框架，具有浮力大、牢固程度高、来源广、经济等优点。水生植物是传统式生态浮床上一个最为重要的一部分，一般所采用的都是湿生植物，菖蒲，鸢尾，美人蕉等能够对水体中的氨、磷和COD等有很好的去除率。将3部分很好的结合在一起，组成了传统式人工浮床，对水质的净化有很好的效果。
组合式人工生态浮床：组合式人工生态浮床是人工浮床的技术的改进，主要包括2种类型，即在植物和浮体的基础上增加基质和在植物，填料和浮体的基础上增加虑食性动物。在人工浮床中加入填料，能够为微生物提供良好的附着生长的环境，通过巨大的比表面积以及附着在填料上面的数量巨大、种类繁多、功能多样的微生物进行新陈代谢对有机物、N、P等吸收，达到水质净化的目的。

2 生态浮床植物的选择原则

由于浮床植物在生态浮床中占有很重要的地位，并且是能够产生经济效益的部分，因此选择合适的浮床植物是保证浮床生态功能实现和产生经济效益的前提，因此，其植物的选择显得尤为重要，应用于生态浮床时，植物的选择一般要遵循以下几个原则[12, 13]：

（1）耐水

由于生态浮床是将陆生或者湿生的植物种植在水面上，因此植物必须能够耐水，只有能够在水面上正常生长的植物，才能发挥其生态治理的作用。

（2）耐污

浮床植物的耐污能力也是一个很重要的选择指标。如果选择的浮床植物不耐污，很有可能会在高浓度污染水体中生长受到抑制甚至死亡，不但起不到净化水体的作用，反而加剧了水体的污染。

（3）比较大的根系表面积

由于浮床植物根系对净化水体污染起到非常重要的作用，其净化能力与其根系表面积密切相关；因此选择浮床植物时，必须考虑植物的根系生长状况，在实际应用时，应该考虑选择根系大、须根多、表面积大的浮床植物。

（4）适应当地的气候水文特点

在实际应用时，选择的物种必须适应当地的气候，水文条件，应该有较好的适应能力，同时不会对当地的生态环境带来危害。

（5）应当具有季节性

在选择浮床植物时，应当考虑浮床植物的季节性，最好能够做到冬季物种和夏季物种搭配组合，以保证浮床能够全年运行，维持其生态功能。

（6）最好具有景观性

所选浮床植物最好具美化功能，用以保证浮床系统的景观效应。

（7）浮床植物能够产生经济效益

在选择浮床植物时，如果能够适当选择一些蔬菜、花卉等具有经济价值的植物，能够使得浮床系统净化水质的同时产生经济效益，会降低浮床系统的运行成本，提高浮床系统推广的积极性。

3 生态浮床研究概况

国际上生态浮床的研究以德国、日本为代表，自从1995年国际湖泊大会以后，该技术得
到进一步认可，并在日本及欧美等国家迅速推广。日本在霞浦湖的士浦港、手賀沼(金相灿等, 2007)、琵琶湖(国家林业局, 2008)等地均有应用，并且取得良好的效果。1990年日本研究者在霞浦（土浦市大岩田）进行隔离水域生物浮床实验，获得了较好的效果[14]。同一时期，美国也利用多种鱼类养殖废水水培生产生菜（Lactuca sativa L.）、西红柿(Solanum lycopersicum E.)、草莓(Fragaria ananassa D.)等蔬菜及风信子(Hyacinthus orientalis L.)等花卉[15]。Vaillant et al. (2003)[16]用浮岛系统栽培毛曼陀罗(Datura innoxia M..)净化修复生活污水，取得较好的效果。德国建设公司用浮床技术栽培芦苇来回收污水中的氮、磷等营养盐及重金属。

我国自从1991年宋祥甫等引入生态浮床技术以后，经过多位学者专家的研究推广，目前已经广泛应用于包括湖泊、水库、城市河道等水体在内的污染治理中。目前国内外对生态浮床的研究根据实验场所的不同可以分为模拟实验和实际应用实验两大类型。在浮床模拟实验方面，主要有静态模拟和动态模拟两种方法。静态模拟主要是以水箱或者小型的水池注入待处理水体模拟实际的水体污染，然后在水体表面覆盖载体，载体上栽种浮床植物，它能够比较好地模拟湖泊等静态的水体生态系统，而且模拟实验一般都能够控制光照、温度等的变化，研究的结果比较可靠，对于研究浮床净化机理很有优势。动态模拟实验重在模拟不同水力停留等条件下，生态浮床的净化效果及对提高净化效率的技术方法的研究。

根据研究重点的不同，目前国内对浮床的研究主要集中在：生态浮床及构建，浮床植物筛选和适应性研究，浮床植物的生理生态，浮床净化富营养化水体的机理，浮床植物对重金属的富集及净化效果，净化模型，工艺设计及水利停留等。国内对生态浮床的研究已经由湖泊水库等静态水体扩展至城市河道小型河流等水体修复，并且已经开始在海洋水体中的研究应用[17]。

参考文献
[1] 卢进登等,人工生物浮床技术治理富营养化水体研究现状. 湖南环境生物职业技术学院学报, 2005(03): 第214-218页.
[2] 加户正治与张东峰, 日本的人工浮岛. 世界科学, 1998(01): 第40页.
[3] 王宁与张雪花. 湖泊富营养化治理的新技术—人工浮岛. 2003. 无锡.
[4] 邴旭文与陈家龙,浮床无土栽培植物控制池塘富营养化水质. 湛江海洋大学学报, 2001. 21(3): 第29-33页.
[5] Billore, S.K., Prashant and J.K. Sharma, Treatment performance of artificial floating reed beds in an experimental mesocosm to improve the water quality of river Kshipra. Water Sci Technol, 2009. 60(11): p. 2851-9.
[6] Sooknah, R.D. and A.C. Wilkie, Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater. Ecological Engineering, 2004. 22(1): p. 27-42.
[7] Tanner, C.C. and T.R. Headley, Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants. Ecological Engineering, 2011. 37(3): p. 474-486.
[8] Van de Moortel, A.M.K., et al., Distribution and Mobilization of Pollutants in the Sediment of a Constructed
Abstract: Ecological floating bed technology is an important constructed wetland technology, compared with other technology, the land was not used, repaired in situ, with the characteristics of environmental friendly, which has proven to have good application effect in the domestic and foreign research. Based on the classification and principle of ecological floating bed, application principle and research at china and abroad on ecological floating bed, this article do some introduction, in order to make more people understand and agree with the ecological floating bed technology.
生态文明视角下鄱阳湖生态经济区现代渔业发展路径研究

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摘 要: 本文基于可持续发展思想, 立足生态服务功能, 从生态文明的视角, 为鄱阳湖生态经济区发展生态渔业提供参考。大力发展生态经济型渔业, 实现渔业生产与生态环境的协调发展是传统渔业向现代渔业发展的必然要求。基于生态文明的视角构建新型渔业经营体系, 创新经营模式和实现产业转型升级, 才能拓展延伸渔业产业链、价值链, 实现做大做强鄱阳湖生态经济区渔业产业和保护 “一湖清水” 的良性互动。

关键词: 生态文明; 鄱阳湖生态经济区; 现代渔业

鄱阳湖生态经济区是以鄱阳湖为核心, 以保护生态、发展经济为重要战略构想的新型经济特区。未来的鄱阳湖生态经济区将逐步建设成为世界性生态文明与经济社会发展协调统一、人与自然和谐相处的生态文明示范区和中国低碳经济发展先行区。国务院已于 2009 年正式批复《鄱阳湖生态经济区规划》, 标志着建设鄱阳湖生态经济区正式上升为国家战略, 对江西绿色崛起具有重大意义。鄱阳湖生态经济区的主导产业集中在现代农业、生态旅游产业和新型工业等方面, 根据鄱阳湖生态经济区资源和产业特点, 渔业具有天然优势, 但深度开发和经营创新存在不足。渔业经营规模小、经营方式粗放、劳动力老龄化、组织化程度低、服务体系不健全等问题, 极大地束缚了鄱阳湖生态经济区现代渔业发展。鄱阳湖是目前与长江保持自然连通状况仅存的二大湖泊之一。不仅集中了长江名优经济鱼类等水产资源, 也是长江鱼苗育肥基地和水生生物种质资源库, 同时是水生物种保护与研究及水生物资源可持续利用的理想场所。鄱阳湖的生态功能定位主要体现在以下几个方面:

1. 主导生态服务功能: 长江流域极其重要的调蓄滞洪区 维系长江中下游水量平衡。
2. 辅助生态服务功能①: 长江中游水域生态平衡的重要功能区 资源持续利用和濒危物种的保护。
3. 辅助生态服务功能②: 国际重要湿地和珍稀候鸟越冬地 履行国际公约和承担国际义务。
4. 辅助生态服务功能③: 重要农副渔业生产基地或重要经济区 经济可持续发展。

鄱阳湖生态经济区现代渔业发展现状

渔业是湖泊生态系统的基本功能之一, 鄱阳湖作为中国第一大淡水湖泊, 长江中下游典型的天然浅水型湖泊和江西省重要的淡水渔业基地, 其渔业功能极其显著。鄱阳湖鱼类调查资料显示, 目前在鄱阳湖已发现 136 种(含亚种)鱼类。但是, 在《中国湖泊志》、《鄱阳湖》和《鄱阳湖研究》均记录 122 种, 《中国五大淡水湖》中为 107 种。资料表明, 2000—2010 年鄱阳湖渔获物平均 3.21 万吨/年。2011 年由江西省人民政府主办, 江西省农业厅承办的第七届江西名优农产品(上海)展示展销会组委会在上海国际农业展览中心召开了新闻发布暨鄱阳湖生态农产品推介会。鄱阳湖水产品开始积极参与高层次竞争, 走品牌化发展道
从鄱阳湖 15 个滨湖区（市、区）渔业经济产业产值来看，近几年，鄱阳湖生态区渔业经济规模稳步发展壮大（见图 1），15 个滨湖县（市、区）渔业经济总产值达到 365.91 亿元，从县域渔业经济产值来看，南昌县、进贤县、余干县和鄱阳县的占比均超过 15 个滨湖县（市、区）渔业经济总产值的 10%，总占比超过 60%（见表）。
鄱阳湖生态经济区现代渔业存在的问题分析

2.1 产业结构不合理, 区域发展不平衡

从渔业经济三次产业产值结构对比来看, 渔业产业结构依旧呈“一大两小”的模式, 即以第一产业为主, 而第二产业和第三产业发展相对滞后。从2013年15个滨湖县（市、区）渔业经济产业产值结构表1中可以看出, 其中庐山区、彭泽县第二产业几乎没有, 新建县第三产业发展非常落后, 占比仅6.5%, 仅南昌县、鄱阳县、都昌县和万年县渔业经济产业结构相对更合理。说明环鄱阳湖区域渔业产业化经营还处于起步阶段, 资源科学合理开发利用、水产品深度加工延伸产业链以及“品牌渔业”发展还不充分。市县之间发展不平衡, 最大产值差比达到近40倍。其中, 鄱阳县的产值最高, 达到近74亿元, 占比达20.22%。庐山区产值最低, 只有近1.87亿元, 占比仅0.51%。排除区位因素的影响, 部分市县渔业缺乏投资大、带动力强的现代渔业项目, 渔业产业转型升级的步伐不够快, 是成为影响这些市县现代渔业产业发展壮大的重要原因。

2.2 鄱阳湖渔业资源持续衰退

根据2011年10月江西省政协人口资源环境委员会和省科学院、省农业厅有关专家所做的《鄱阳湖渔业资源利用与保护专题调研报告》统计, 2011年鄱阳湖区有捕捞渔船3万艘, 渔业人口16万人, 其中, 持证渔船1万艘, 渔业人口近7万人, 其捕捞强度已经大大超过了鄱阳湖的承受能力。近年来长期极端的低水位改变了鄱阳湖的生态环境, 入湖水量减少, 使局部江湖水交换不畅, 削弱了湖泊对污染的净化能力, 使鄱阳湖湖区部分水体难以保持良好的水质, 区灾害损失残载能力变弱, 难以保证最小生态需水量, 自净能力下降。鉴于水位下降对鄱阳湖湖滩显现的影响, 极端低水位对鄱阳湖湿地结构和功能的长期效应不容忽视。大量吸螺采蚌不但吸走了大量螺蚌, 也严重破坏了湖底的水草和水质, 导致鱼虾数量急剧减少。

2.3 鄱阳湖渔业存在的生态问题

2011年, 江西省生态学会组织专家, 就鄱阳湖生态现状进行了专题调研, 对鄱阳湖生态的评价结果是：

| 县名 | 产值（元） | 占比 | 第一产业 | 第二产业 | 第三产业 | 占比 |
|------|------------|------|-----------|-----------|-----------|------|
| 星子县 | 73701.00 | 2.01% | 41166.00 | 55.86 | 17540.00 | 23.80 |
| 都昌县 | 280246.20 | 7.66% | 78866.20 | 28.14 | 141884.00 | 50.63 |
| 湖口县 | 108777.30 | 2.97% | 61352.30 | 56.40 | 31687.00 | 29.13 |
| 彭泽县 | 107172.75 | 2.93% | 82746.20 | 77.21 | 2414.00 | 2.25 |
| 共青城 | 23311.10 | 0.64% | 13967.10 | 59.92 | 2510.00 | 10.77 |
| 余干县 | 530468.00 | 14.50% | 235683.00 | 44.43 | 112581.00 | 21.22 |
| 余江县 | 739971.00 | 20.22% | 238154.00 | 32.18 | 291822.00 | 39.44 |
| 万年县 | 98563.00 | 2.69% | 28118.00 | 28.53 | 32608.00 | 33.08 |
| 总和 | 3659076.15 | 100% | 1538144.10 | 42.04 | 1175064.00 | 32.11 |

表1 2013年15个滨湖县（市、区）渔业经济产业产值结构

数据来源：江西省渔业统计资料（2013年）
总体处于安全水平，接近不安全边缘，存在一些生态问题不容忽视。一是鄱阳湖生态建设规划滞后，管理体系还不健全，缺乏合力，难以实现高效持续的科学管理；二是再生公共资源管理普遍存在的“公地悲剧”现象，就如亚里士多德所言：“那由最大人数所共享的事物，却只得到最少的照顾”；三是鄱阳湖持续完整深入的科学研究尚有不足，基础理论与先进技术应用出现短板问题；四是生态保护的公众参与生态补偿机制有待进一步补充和完善。

3 鄱阳湖生态经济区现代渔业的发展路径选择

近年来，上海等发达地区渔业加快实现战略转型取得了明显的经济、社会和生态效益。渔业产业化是以国内外市场为导向，按照市场经济规律，通过“市场+龙头企业+合作社+养殖基地+中介组织+渔民”的形式，逐步形成产供销一体化的生产经营体系。产业升级是现代经济发展的共同追求，产业转型升级与环境保护良性互动也成为当前的研究热点之一。总体来看，江西产业转型升级未能摆脱做大经济总量与保护生态环境、保护青山绿水相互矛盾的不利局面。因此，发展鄱阳湖生态经济区现代渔业应从构建新型渔业经营体系，实现现代渔业产业转型升级和保护生态环境统筹考虑。笔者基于可持续发展思想，立足生态经济，从生态文明的视角，构建了鄱阳湖发展生态渔业的理念模型（如图2）。加快探索走出一条“特色是生态、核心是发展、关键是转变发展方式、目标是生态与经济协调发展”的鄱阳湖生态经济区现代渔业之路。具体发展路径如下：

图2 鄱阳湖生态经济区现代渔业发展理念模型

3.1 核心吸引力——实施鄱阳湖渔业品牌战略

以“鄱阳湖”品牌统领鄱阳湖生态经济区现代渔业，确立品牌生态位，打造奢侈级、精品级和大众级水产品。当前互联网营销已成为一种重要的品牌推广路径，笔者认为，其关键在于互联网的大空间同步支撑了大众的从众心理，实现了品牌营销的时尚化和品味化。鄱阳湖生态经济区现代渔业可以选择互联网营销路径扩大“鄱阳湖”品牌影响，采取政府支持，企业主导，渔民参与的方式全面推介鄱阳湖生态经济区现代渔业的“风光”、“风情”、“风味”和“风俗”，走品牌引领市场，企业打造产品，渔民经营故事的新型发展道路。

3.2 核心驱动力——加大现代渔业产业转型升级力度

从鄱阳湖生态经济区现代渔业的发展阶段特征看，必须实现渔业的大投入、大建设、大发展，培育和
引进重大渔业产业项目，加大渔业技术和经营创新力度，促进渔业企业集聚、产业链延伸，打造一批
在全国甚至全球具有竞争力和影响力的渔业知名企业与特色渔业生态园区。

### 3.3 核心生命力——鄱阳湖渔业与生态文明的统一

资源节约与环境保护是我国的一项基本国策。产业成长要以“循环、生态、低碳”为宗旨，走资源节约
和环境保护之路。生态渔业建设是在根据生态学原理进行的人工设计的基础上，充分利用现代科学技术
和生态系统的自然规律，对受人为活动干扰和破坏的渔业生态系统进行恢复和重建，实现环境、经济、社
会效益的统一。鄱阳湖生态经济区渔业发展必须以生态控制理论和生态创新理论为指导，用系统整体性的
观点构建区域生态经济型渔业系统，充分发挥鄱阳湖生态经济系统的各项功能，进而使区域形成良性循环
的生态渔业产业系统。发展以产业化为基础的生态渔业是实现充分利用渔业资源和实现渔业高产、高效、
持续发展，从而达到生态系统与经济系统的良性循环和经济、生态、社会三个效益的统一的有效途径。
同时，在管理和服务等方面还必须做到生态化管理和服务。大力弘扬生态文明，挖掘和传承鄱阳湖渔业文化
底蕴，发展富有鄱阳湖渔业特色的文化艺术产品。

参考文献
[1] 刘镭. 农业经营方式的选择行动与社会结构互动关系研究[J]. 中南民族大学学报( 人文社会科学版), 2014, 34(2): 93-97.
[2] 王国平. 产业升级模式比较与理性选择[J]. 上海行政学院学报, 2014, 15(1): 4-12.
[3] 卢福财，朱文兴，胡平波. 产业转型与环境保护良性互动影响因素研究——以江西为例[J].江西社会科学，2014, 1: 56-61.
[4] 姜长云.关于构建新型农业经营体系的思考——如何实现中国农业产业链、价值链的转型升级 [J]. 学术前沿，2014, 1: 70-78.
[5] 甘江英，吴斌. 江西水产品牌营销现状及对策研究[J]. 中国水产, 2014, 4: 32-34.
[6] 罗贤宇, 俞白桦, 曾丽萍. 鄱阳湖生态经济区生态农业发展策略研究[J].福建农林大学学报( 哲学社会科学版) , 2014, 17( 1): 22-26.

The research about modern fishery development path of Poyany lake ecological economic zone from the perspective of ecological civilization

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Abstract: In this paper, based on the idea of sustainable development and the ecological service function, from the perspective of ecological civilization, to provide reference for the development of ecological fishery in the ecological economic zone of Poyang Lake. Vigorously developing the ecological economy fishery, To achieve the harmonious development of fishery production and the ecological environment is the inevitable requirement of the traditional fishery to the development of modern fishery. Building new fisheries management system based on the perspective of ecological civilization, business model innovation and to achieve the industrial transformation and upgrading, to expand the fishery industry chain, value chain. To realize the benign interaction between the bigger and stronger Poyang Lake Ecological Economic Zone fishery and protection "a lake of water."

Keywords: Ecological civilization, Ecological economic zone of Poyang Lake, Modern fishery
小波分析在鄱阳湖水位序列的多时间尺度分析中的应用

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摘 要：以鄱阳湖为研究对象，运用 Morlet 连续复小波函数分析星子水文站 1953-2012 年历年年均水位变动的多时间尺度演变特征，并在水位变动的小波方差分析结果的基础上运用 surfer8.0 绘制出控制鄱阳湖历年年均水位演变的主周期趋势图，结果表明：(1) 在不同时间尺度的分辨率条件下，鄱阳湖历年年均水位序列显现出不同的周期交替现象，在鄱阳湖历年年均水位演变过程中存在着 25-32 年，19-23 年，8-15 年以及 3-7 年 4 类时间尺度的周期变化规律，且这 4 类周期的强弱程度和分布情况以及突变点均不相同；(2) 鄱阳湖历年年均水位变动存在 3 个较为明显的峰值，依次对应着 28 年、22 年和 5 年的时间尺度；(3) 三类时间尺度具有较为明显的局部化特征，在 28 年特征时间尺度上，年均水位变动的平均周期为 19 年左右，在 22 年特征时间尺度上，年均水位变动的平均变化周期为 15 年左右，在 5 年特征时间尺度上，年历年均水位变动的频率变化较为快速，同时振荡行为也较为明显。关键词：历年年均水位；Morlet 小波；星子站；鄱阳湖

前言

随时间变量 t 变化的水文要素 y(t) 在 t1, t2, ..., tn 处的观测值 y(t1), y(t2), ..., y(tn), ..., 组成的离散有序集合，称为一个水文时间序列，记作 {y(t)}。水文时间序列随时间的变化受多种因素的共同影响作用，并且大都属于非平稳序列，它既包括受确定性因素影响的确定性成分，比如周期成分、趋势成分以及突变成分等，同时又包括受不确定性因素影响的随机成分。传统意义上的水文时间序列分析方法建立在数理统计的随机水文学理论基础之上，但是由于现实自然界中的水文现象十分复杂，加之水文系统的非线性、时刻变化、分布不确定性等特点，传统的水文时间序列分析方法在实际应用中的局限性相对也比较突出，以滑动平均模型为例，参数估计的复杂性是该方法存在的致命缺点。小波分析技术是一种研究水文序列变化特性的新兴且相对有效的分析方法。小波分析在水文时间序列分析中一个最主要的应用就是运用多时间尺度分析研究水文序列的变化趋势和周期等组成。多时间尺度是指在系统变化中并不存在真正意义上的周期性，而是时而以某种周期变化，时而又以另外一种周期变化，并且在不同时段中又包含各种时间尺度的周

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期变化[6]。在实际应用中主要是利用小波变换将非平稳时间序列分解为在原始序列平滑得多的序列，然后对分解后的序列进行分别研究[7]。小波分析法可以清晰地提取出隐藏在水文时间序列中的多种变化周期，充分反映系统在多种不同时间尺度中的变化趋势，并能对水文系统未来发展趋势进行定量化。从小波分析产生至今其在水文学的及水资源学研究中的成果较多。郑显等[8]将小波分析引入随机水文过程研究领域，基于水文现象产生的自动成因，对水文序列进行小波变换，以测定量水文序列蕴含的近似周期。王文圣等[9]总结了小波分析在水文学中的应用研究现状和未来研究趋势及发展方向。Kan & Lin[10]则利用小波变换方法的时、频局部化的特征对美国的一个典型农业流域的水文和水质状况进行了分析研究，结果表明小波分析法可以有效的用于分析细节时间空间的非平稳水文序列和不同时间尺度的水质信号。

本文以鄱阳湖为研究对象，以星子水文站为代表分析鄱阳湖大湖面水文情势变化，水文（历年年均水位）数据时间序列从1953-2012年，共计序列长度为60年（吴淞基面，m），由江西省鄱阳湖水文管理局提供。应用小波分析技术分析鄱阳湖水文时间序列的多时间尺度特征，以期揭示鄱阳湖多年水位变化的周期性和规律性，从而为鄱阳湖水资源管理及调度提供一定的参考依据。

2 鄱阳湖水文的多时间尺度分析

2.1 小波函数的选择与确定

在对水文时间序列进行小波分析之前须选择好恰当的基小波函数，换句话说，选择合适的基小波函数是水文时间序列进行小波分析的前提。主要原因是在实际应用研究中，即便是针对同一水文时间序列，如果选择基小波函数不同，最后所得到的分析结果往往也会有一定的差异，有的时候甚至会得到很大的差异。基于水文情势包含多时间尺度的变化特征以及受到多种影响因子的共同作用，本文选取Morlet连续复小波变换来分析鄱阳湖水文序列的多时间尺度特征，主要原因是：①在水位变动过程中含有多时间尺度变化特征，并且这种变化常常都是连续的，故需采用连续小波变换对水文时间序列进行分析；②对实小波变换而言，实小波只能给出水文时间序列变化的正负及振幅范围，而复小波则不然，它能够提供水文时间序列变化的位相和振幅两方面的信息，且有利于对水文系统作进一步分析研究；③复小波函数的实部和虚部差为π/2，可以消除当用实小波变换系数作为判断依据而产生的虚假振荡，从而使分析结果更为准确[5-6, 11]。基于上述三种优点，故本文选择Morlet连续复小波函数。Morlet小波是高斯包络下的单频率复正弦函数，Morlet小波为复数小波，其定义为[12]：

$$\varphi(t) = e^{-it^2/2}e^{it/2}$$  (1)

2.2 水位序列处理

鄱阳湖水文情势变化除主要受赣江、信江、修河、饶河及鄱湖（“五河”）与长江来水双重影响之外，同时也受到湖盆形态、地形地貌、气象条件及土壤植被等多因子的共同影响，在其固有的相关性和周期性的基础上，也伴随有较大的随机性，表现出较强的非线性特点[13-15]。因此，对鄱阳湖星子水文站历年年均水位时间序列进行小波变换以前，首先须利用matlab9.0软件中的小波分析包工具对年均水位序列两端数据进行一定长度的延伸，从而减小或者消除序列开始点和结束点附近的边界效应。在进行完小波变换之后，去掉两端延伸
数据的小波变换系数，从而保留原年均水位数据序列时间段内的小波系数。然后对年均水位序列进行 Morlet 复小波变换分析；再运用 Excel 2003 计算得到水位序列小波变换方程的小波系数；最后借助 Surfer 8.0 软件绘制出鄱阳湖水位时间序列的小波系数实部等值线图，并通过对小波系数进行分析得到鄱阳湖历年年均水位的时间演变特征。

3 结果分析

小波系数实部等值线可以用于反映水位变动在不同的多时间尺度周期变化以及其在时间域中的分布，并在此基础上能够判断出在不同时间尺度上，鄱阳湖水位变动特征及趋势。不同时间尺度的鄱阳湖历年年均水位变化特征可以由不同时间尺度的小波系数反映出来。如小波系数为正数则对应鄱阳湖年均水位升高；反之，为负数则对应鄱阳湖年均水位下降；如果小波系数为零则对应着突变点，表示这个在这个点的前后鄱阳湖年均水位变化必然不同。小波系数的绝对值越大则表明该时间尺度变化越为显著。从图 1 中可以看出鄱阳湖历年年均水位变动在不同时段表现出不同的周期变化和交替变化, 总的来说在鄱阳湖历年年均水位演变过程中存在着 25~32 年, 19~23 年, 8~15 年以及 3-7 年的 4 类尺度的周期变化规律。

![图 1 鄱阳湖历年年均水位序列 Morlet 小波系数时频图](image)

**图 1 鄱阳湖历年年均水位序列 Morlet 小波系数时频图**

Fig.1 The time and frequency graph of Morlet wavelet coefficients of the mean annual water levels in Poyang Lake

Morlet 复小波系数的模值能够揭示在不同时间尺度变化周期所对应的能量密度在时间域中的分布，且模值越大，表明与之相对应的时段或者尺度的周期性就越强。从图 2 可以看出，鄱阳湖 1953-2012 年的历年年均水位变动过程，25-32 年时间尺度模值最大，说明该时间尺度周期变化最明显，19-23 年时间尺度的周期变化次之，接下来是 8-15 年的变化周期，其他时间尺度的周期性则变化比较小。
Morlet 复小波小波方差分析图可以揭示水位时间序列的波动能量随着时间变化的分布特征。图 3 可以看出，鄱阳湖历年年均水位变动的小波方差图中存在 3 个较为明显的峰值，它们依次对应着 28 年、22 年和 5 年的时间尺度。其中，最大峰值对应着 28 年的时间尺度，说明 28 年左右的周期震荡最强，为鄱阳湖历年年均水位变动的第一主周期；22 年时间尺度对应着第二峰值，为鄱阳湖历年年均水位变动的第二主周期，第三峰值分别对应着 5 年的时间尺度，鄱阳湖历年年均水位变动的第三主周期。从而可以得知，以上 3 个周期的波动控制着鄱阳湖历年年均水位在整个时间域内（1952-2012 年）的变化特征。
在小波方差检验的结果的基础上，绘制出控制鄱阳湖历年均水位演变的主周期趋势图（图4）。从主周期趋势图中能够分析出在不同时间尺度下，鄱阳湖水位变动存在的平均周期以及高-低水位的水位变化特征。可以计算出，在28年特征时间尺度上，水位波动变化的平均周期为19年左右，大约经历了3个高-低水位转换期；而在22年特征时间尺度上，水位波动的平均变化周期为15年左右，大约经历了4个周期的高-低水位变化；而在5年特征时间尺度上，历年均水位波动变化频率比较快速，且波动趋势呈较为稳定的状态。小波分析技术既能够将隐含在水位时间序列中各种随时间变化的周期振荡较为清晰地突显出来，又可以反映鄱阳湖历年均水位波动的变化趋势，从而对其年均水位波动未来演变趋势作一个定性的估计。

图4 鄱阳湖历年均水位的不同特征时间尺度小波实部过程线

Fig.4 The Morlet wavelet real process line of the three time scales of the mean annual water levels in Poyang Lake

4 讨论

周期性水文过程作为构成湿地要素的三大要素之一，对湿地生态系统结构和功能具有重要的影响，尤其是在湖泊湿地中，水文过程通常是决定湿地植被分布的主导因素[16-17]。鄱阳湖作为具有国际性保护意义的重要湖泊湿地，其年内和年际间水位变化巨大且变化在国际的湖泊中都十分罕见。因此，基于鄱阳湖的特殊性和区域性，关于鄱阳湖水文过程的研究已有大量的文献报道，对鄱阳湖周期性水文过程的研究已经相对比较成熟[15, 18-19]。然而，由于鄱阳湖水位受长江和“五河”来水的双重影响，鄱阳湖水文过程变化十分复杂，至今也没有有关文献能够准确定性和预测出鄱阳湖水文过程的内在演变机制及发展趋势。可以确定的是，尽管鄱阳湖逐日和逐月水位变动受降水和季节等因素作用而显得没有较明显的规律性；但是对于鄱阳湖历年均水位序列而言还是存在一定的周期性[18-19]。以往对鄱阳湖水位变动周期研究大部分是依据实测数据资料和时间序列一一对应建立的“水位—年份”关系示意图（图5），从而在示意图上确定鄱阳湖历年均水位序列的周期性。从图5中也可以看出鄱阳湖历年均水位序列（1953-2012年）大约存在28年的周期性，跟小波分析方法得到的分析结果相一致。然而较小波分析方法来说，运用图5方法确定的鄱阳湖历年均水位的周期性并不是很直观，而且不能确定在特征时间尺度上水位波动变化的平均周期。因此，运用小波分析方法确定的鄱阳湖历年均水位序列的周期性更加科学，且能够提取水文序列中更多的隐藏信息。
由于水文时间序列的复杂性以及容易遭受随机因素干扰的特性，水文过程的时间序列并非是按照严格的周期序列开展的，水文时间序列中往往都会存在异常的信号，即小波分析技术中所谓的“噪声”\(^{[20]}\)。因此在对鄱阳湖水文时间序列的多尺度分析中，首先须考虑到噪声因素对周期分析结果的可能产生的不利影响，接着运用消噪措施来减小或者消除噪声对分析结果产生的影响。本研究借以对鄱阳湖年均水位时间序列的两端进行一定长度的延伸，来减小或去除水文时间序列的开始点和结束点附近产生的边界效应。此外，在对水文时间序列进行小波分析之前选择好恰当的基小波函数，也是减小噪声对结果产生不利影响的一种有效方法。故本研究依据鄱阳湖水文过程的动态变化特征，选取 Morlet 连续复小波变换分析鄱阳湖历年年均水位变动的多时间尺度特征具有一定科学性和合理性。

5 结论

（1）借助小波分析时、频局部化的特性，可以较好的应用于鄱阳湖历年年均水位的多时间尺度分析，分析得到的结果较传统的分析方法更具有科学性及可行性，且能够发掘水文时间序列中更多的隐藏信息。

（2）鄱阳湖星子水文站历年年均水位时间序列存在着多种时间尺度，且同时大时间尺度包含着小时间尺度，每种时间尺度均蕴含着鄱阳湖历年年均水位波动的变化规律。

（3）周期性水文过程的精确确定，有助于进一步揭示鄱阳湖水位变动的内在演变机制及发展趋势，对维持鄱阳湖生态水文过程，降低区域洪涝灾害风险能够一定的参考依据。

参考文献

[1] 汤成友，官学文，张世明. 现代中长期水文预报方法及其应用[M]. 中国水利水电出版社, 2008.

[2] 丁晶，邓育仁. 随机水文学[M]. 成都: 成都科技大学出版社, 1988.
[3] 李荣峰, 冀雅珍. 水文时间序列分析计算方法的研究进展与展望[J]. 山西水利科技, 2005, 4: 4-6.
[4] 王文圣, 丁晶, 李跃清. 水文小波分析[M]. 北京: 化学工业出版社, 2005.
[5] 汪燕芳, 王栋. 水文序列小波分析中小波函数选择方法. 水利学报, 2008, 39(3): 295-300.
[6] 王卫光, 张仁泽. 小波分析在地下水位序列多时间尺度分析中的应用[J]. 武汉大学学报(工学版), 2008, 41(2): 1-5.
[7] 吴爱杰, 王志生, 董雅国. 小波分解与变换法预测地下水位动态[J]. 水利学报, 2004, 5: 39-45.
[8] 郑显, 张间胜. 基于小波变换的洪水序列的近似周期检测法[J]. 水文, 1999, 19(6): 22-25.
[9] 王文圣, 丁晶, 向红莲. 小波分析在水文学中的应用研究及展望[J]. 水科学进展, 2002, 13(4): 515-520.
[10] KANG S, LIN H. Wavelet analysis of hydrological and water quality signals in an agricultural watershed [J]. Journal of Hydrology, 2007, 338(1): 1-14.
[11] 项文武, 胡铁松, 吕美朝. 基于 Morlet 小波的ET0序列多时间尺度分析[J]. 武大科学(工学版), 2009, 42(2): 182-185.
[12] 张少文, 丁彪, 廖杰, 等. 基于小波的黄河上游天然年径流变化特性分析[J]. 四川大学学报(工程科学版), 2004, 36(3): 32-37.
[13] 张丽丽, 于汛遥, 蒋云钟, 等. 鄱阳湖自然保护区湿地植被群落与水文情势关系[J]. 水科学进展, 2012, 23(6): 768-775.
[14] 闵骞, 方腊生. 1952-2011年鄱阳湖湖水变化分析[J]. 湖泊科学研究, 2012, 24(5): 675-678.
[15] 叶思春, 李相虎, 张伟. 长江中下游鄱阳湖的时期变化特征及其影响因素[J]. 西南大学学报(自然科学版), 2012, 34(11): 69-75.
[16] 胡振鹏, 葛海刚, 刘成林, 等. 鄱阳湖湖水生态系统结构及湖水位对其影响研究[J]. 长江流域资源与环境, 2010, 19(6): 597-605.
[17] 刘永, 郭怀明, 周丰, 等. 湖泊水位变动对水生植被的影响机理及其调控方法[J]. 生态学报, 2006, 26(9): 3117-3126.
[18] 闵骞. 鄱阳湖湖水位变化规律的研究[J]. 湖泊科学研究, 1995, 7(3): 281-287.
[19] 郭华, Hu Qi, 张伟. 近 50 年来长江与鄱阳湖水文相互作用的变化[J]. 地理学报, 2011, 66(5): 609-618.
[20] 王红瑞, 叶乐天, 刘昌明, 等. 水文序列小波周期分析中存在的问题及改进方式[J]. 自然科学进展, 2006, 16(8): 1002-1008.
Multi-time-scale analysis of water level series with wavelet transform in Poyang Lake

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Abstract: Poyang Lake is China’s largest freshwater lake. The water level variation of Poyang Lake has been one of the hot issues in the last decades. The mean annual water levels from 1953 to 2012 in Poyang Lake were selected as the study object. Complex continuous Morlet wavelet was conducted to study the multi-time-scale variation characteristic of water level fluctuations. Based on the wavelet variances, the primary period trend graph that controlled the mean annual water level fluctuations of Poyang Lake was drawing out by surfer8.0. The result show that there are four cycle variations (i.e. years of 25-32, 19-23, 8-15, 3-7) in the mean annual water level fluctuations in Poyang Lake. The strength and distribution of each cycle variation is different as well as the catastrophe point. The mean annual water level fluctuations are mainly in the presence of three conspicuous peaks, which are in correspondence with the time scales of years of 28, 22 and 5 in Poyang Lake. Each different time scale has apparently localized features. In the 28-year time scale, the mean water level fluctuation cycle is about 19 years, and the 22-year time scale is with about 15 years. But as to the 5-year time scale, the water level fluctuation changes more frequently and oscillates more significantly.

Keywords: Mean annual water level fluctuation; Morlet wavelet; Xingzi hydrological station; Poyang Lake
涨渡湖江湖联系运行初报

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第一作者简介：胡皓，1986 年出生，2006 年湖北生态学院毕业后一直在基层从事湿地保护工作，参与了《涨渡湖湿地自然保护区总体规划》和《涨渡湖湿地自然保护区科学考察报告》等调查起草工作，在江湖联系、社区共管、水流域综合治理、疫源疫病监测等方面都有研究，在《湿地科学研究》、《湖北省生态学院学报》、《湖北林业经济》等刊物上多次发表湿地保护方面的论文。

摘要：涨渡湖是长江中游北岸一个典型的湖泊，1954 年长江大堤的修建让江湖从此相隔。为了改善湿地生态环境，保护湿地生物多样性，在世界自然基金会（WWF）的帮助下，从 2005 年开始，涨渡湖联通江湖开启挖沟大闸，且在各项管理机制上进行了成功探索。本文对相关管理机制的运行进行了分析，剖析了存在的问题，提出了完善建议。

关键词：湖泊湿地; 江湖联系; 运行机制

1 前言

据考证，长江中下游干流河道，除湖南的洞庭湖和江西的鄱阳湖到现在还与长江保持自然连通外，其它湖泊基本上用堤防和闸口将长江干流与湖泊及湿地人为地分割开来。长期以来为了生存和发展，修堤建闸、抵御洪水、围湖造田是我国传统的治河理念，逐渐形成了现在的江湖阻局，造成了湿地生态萎缩。随着经济的快速发展和人口的不断增长，长江流域湿地生态系统面临越来越严重的威胁，涨渡湖也经历了这个过程。

世界自然基金会（WWF）秉承维护江湖湿地生态系统稳定的理念，2003 年同武汉市新洲区人民政府签署了保护涨渡湖湿地合作框架协议，将涨渡湖列为长江示范项目（WWF—HSBC）示范区，与相关部门和科研机构单位一起，开展了一系列“重建江湖联系，恢复长江生命之网”活动，重点实施了以“灌江纳苗”为主要内容的季节性江湖联系，并且形成和完善了一系列保证这些活动正常开展的运行管理机制。

2 涨渡湖地区湿地自然概况

2.1 地理位置及结构

武汉市新洲区位于湖北省的东部，长江北岸，是武汉市的新城区，境内“四岗”（仓阳、长岭、叶顾、楼寨）和“三河”（举水、倒水、沙河）并行排列，西南部以涨渡湖和武湖为代表的众多湖泊星罗棋布。据查，解放初期，全区湖泊个数达 37 个，以高程 19 米为常年水位概算，湖泊常年水面 316.7 平方公里。经过近 20 年的整治，境内面积达 0.67 平方公里的湖泊只有 6 个，且大多都由人工堆坝加以固定，常年水位面积只有 55 平方公里。到 1974 年止，涨渡湖被人为分割成涨渡湖、陶家大湖和七湖 3 个湖泊，这 3 个湖泊之间依靠 5 个节制闸季节性连通，这 3 个湖泊与主港、举水、倒水、长江之间依靠 9 个节制闸季节性连通，形成了南部地区水功能调度的人工系统。

2.2 涨渡湖自然概况

涨渡湖位于新洲区的南部，上世纪 50 年代之前湖泊与长江自然相连，1954 年修建的长江大堤让江湖隔堤相望，加上 50 年代至 70 年代大规模的湖区开发围湖造田，涨渡湖面积由原来 255 平方公里锐减到现在的 37.7 平方公里。人们再也看不到“落水为湖、涨水为渡”的独特景象了。

涨渡湖地质属新构造运动沉降区，为长江、举水、倒水之间平原与冲积平原，围湖造田之前的
承雨面积达 6371 平方公里。经改造涨渡湖东、南、北等三方为人工堤坝所固定，堤坝平均高程 23 米，西方部分为自然高地，现有水面 37.7 平方公里，平均水深 1.3—1.5 米，最大水深 2.3 米，湖底高程 16.7 米。湖面呈准正方形，常年调蓄水位为 20 米，养殖最低水位为 18.7 米，东北角齐头咀节制闸通往十里主港，主港东西分别由沐家径闸和蔑扎湖闸通过举水和倒水通往长江，南边则通过近 1 公里的挖沟渠和挖沟闸连通长江。长江主汛期湖泊控制水位为 19.20 米，汛期时调蓄水位控制在 19.5 米之内，排涝调蓄量为 3600 万立方米。以上结构和指标均为涨渡湖江湖联系，实施灌江纳苗的主要条件。

2.3 涨渡湖面临的生态环境形势

江湖阻隔以及城市化进程造成的污染，使湖泊湿地面积和功能萎缩，湖泊水体自净能力下降，“地球之肾”名不符实，流动的湖水在一定程度上加剧了湖泊生态的恶化。因湿地水系被人为割裂，自然状况被破坏，鸟类资源锐减，特别是东方白鹳、白鹤这些过去常见珍贵鸟类在涨渡湖连续 10 年没有发现，而湖中自然生长的野生菱疯长，覆盖率达 70%。农业面源污染导致湖泊水质不断下降，无序养殖、投肥养殖、单品种养殖在一定程度加重了湖泊水体富营养化。严酷的事实告诉我们：维护江湖的自然生态系统对人类可持续发展极为重要，保持湖泊生态的综合价值远远超过围湖造田的农业价值。

2.4 涨渡湖生态修复的必要性

水体的连通联系是一种有机的动态联系，可以为生物的栖息、繁殖、迁徙提供更多通道，增强水体的生物多样性，优化水生态环境；从另一个方面来认识，水体的连通增加了系统的复杂特性，使其更具抗逆能力。目前涨渡湖中的鱼类多为“四大家鱼”，其它一些鱼类也是人工饲养的，野生种很少且很难形成群落，鱼类种群及结构相当单一。水生植物群落结构不尽合理且不稳定，不具备良好的生态效益，涨渡湖缺少了应有的基本功能。因此，开展以“灌江纳苗”为主要内容、以丰富生物多样性为主要目的涨渡湖江湖联系具有十分重要的意义。

3 涨渡湖江湖联系的运行模式

2005 年 6 月 15 日，新洲区人民政府在长江大堤举行首次江湖联系仪式，省、市、区领导和 WWF 的官员共同按下电钮，开启了挖沟大闸，滚滚长江活水直奔涨渡湖。与此同时，3 艘渔政船驶往江心，大家一起动手向长江增殖放流人工培养的鱼苗 1020 万元。从这年开始，地方政府每年 6—7 月都会在涨渡湖举行隆重开闸仪式，开展以“灌江纳苗”为主的江湖联系活动，同时进行人工增殖放流。江湖联系，灌江纳苗在涨渡湖已经正常运行了十年。

3.1 运行保障

3.1.1 成立机构

在 WWF 的帮助支持下，根据涨渡湖湿地自然保护区的发展实际，2005 年 4 月 9 日，新洲区人民政府成立了“涨渡湖湿地自然保护区共管委员会”。管委会的成立为搞好涨渡湖的各项工作提供了组织保障。管委会的委员来自林业、水务、农业、环保、卫生等政府部门，还有相关村、渔场和科研单位的代表，管委会主任由区人民政府分管副区长担任，组成成员形成领导集团，负责保护区的管理工作。

3.1.2 出台方案

2006 年 5 月 8 日，新洲区人民政府印发了《涨渡湖江湖连通运行方案》，对涨渡湖开展以“灌江纳苗”为主要内容的江湖联系以政府的名义进行了制度性的规范。方案对运行程序、各相关单位相关责任、活动经费等作了详尽规定，确保了涨渡湖江湖联系的健康运行。

3.2 技术参数

江湖联系是一项技术含量较高的工作，根据涨渡湖的实际对安全开展江湖联系在技术上作出了
详细规定。主要指标为：江汉关水位 25 米高程以下，涨渡湖地区没有内涝，主港水位在 18.5 米高程以下，流量 10 立方米 / 秒，流速 0.2 米/秒，时间不超过 96 小时，以涨渡湖水面上升 0.4—0.5 米为限。

3.3 部门合作

在每年的 4 月，由区政府办牵头召开涨渡湖江湖联系专题协调会议，明确各相关职能部门在江湖联系过程中的具体分工。主要有：水务部门及时上报长江和涨渡湖水文情况，准确预测适合江湖联系水文条件的时期；农业水产部门准确测定长江鱼苗苗汛期；卫生部门做好血吸虫监测，预防和应急方案制定和落实；林业部门作为湿地职能主管部门协助区政府做好协调工作。

4 涨渡湖江湖联系运行存在的主要问题

4.1 技术要求过高

开展江湖联系所设置的主要技术参数要求过高，水文和苗汛时期的把握很难在合适的时间相遇，几大技术参数同时具备操作起来难度很大。

4.2 公众参与不足

十年来，涨渡湖开展江湖联系都是在政府部门和上级单位以及科研部门的直接主持和督促下开展的，对涨渡湖地区与湖泊息息相关的公众的意见很少听取。

4.3 协调机制不活

湖泊管理部门主体众多，涉及的相关部门多站在本部门的利益上考虑问题，同时部门利益、地方利益交织，保护受掣，管理缺失，无章可循，“多龙管水”结果是谁也管不好水，机构能力较弱，缺乏监督管理体系，地方政府有“力不从心”的感觉，协商、协调机制有时很难有较好的效果。

4.4 后续措施不力

江湖联系实施十年，极大地改善了涨渡湖的水生态环境，丰富了涨渡湖的生物多样性，加上对涨渡湖水产养殖的限制，水体除个别指标超标外，基本保持在三类水质。但是江湖联系带入涨渡湖的泥沙没有相关措施加以改善，带入涨渡湖的有害生物缺乏足够的监控手段，这些也成为涨渡湖生态危机的又一潜在因素。

5 优化涨渡湖江湖联系运行机制的对策

建立涨渡湖江湖联系动态运行机制是从根本上保护涨渡湖湿地生态，实现涨渡湖地区社会经济与生态环境可持续发展的重要措施之一。结合涨渡湖的实际提出以下优化涨渡湖江湖联系运行机制的对策。

5.1 加大宣传力度

广泛开展宣传活动，提高公众参与度，收集整理消化涨渡湖地区居民对江湖联系的相关意见，鼓励公众对江湖联系机制提建议，提高公众环保意识，让他们真正成为湖泊的主人。

5.2 组建专管机构

参照洪湖、龙感湖的做法，组建独立于林业、水务、农业、环保、卫生等部门之外的湖泊湿地管理机构，政府依法授权，履行江湖联系等湖泊保护和执法职能。

5.3 做好综合规划

生态修复规划先行，在坚持公平性、持续性原则，自然资源和环境、社会与经济的协调发展基础上，以水环境生态改善为中心，结合居住、文化、景观、经济等生态功能建设要求，做好涨渡湖地区水生态综合规划。这个规划要突出以人为本，顺应自然，保持生物多样性综合平衡，有机统一，高效和谐，着眼当前，适度超前等特色。
5.4 丰富技术内涵

5.4.1 严防虲螺的迁移扩散

涨渡湖地区是已经成功消灭了血吸虫的地区，公众对血吸虫有极强的畏惧心理，现实中也有感染的病例，要充分发挥涨渡湖挖沟通道内阻螺池的作用，确保正常运行，并且全年监测和预防药具的发放不能停止。

5.4.2 着手研究泥沙输入问题

长江为多沙河流，在涨渡湖实施江湖联系必然会遇到泥沙输入问题，涨渡湖水较浅，容量有限，若无防沙输入措施，必然会造成湖泊积淤，加速涨渡湖萎缩，所以研究和应用江水入湖前的防沙措施意义十分重大。

5.4.3 形成水生生物监测机制

每年定期对涨渡湖地区水生生物进行监控，科学统计分析，找到江湖联系前后的变化规律，及时发现和处理有害生物对涨渡湖地区生物多样性的破坏，比如苦旱莲子草、水葫芦等。

5.5 修缮通江通道

维修挖沟闸和沐家径闸的两个阻螺设施，确保运行正常。对七湖至涨渡湖、陶家大湖至七湖两条港道进行疏浚与治理，对盛牛皮闸、水产队大闸、胡咀闸、龙王咀闸、龙王咀溢洪闸等5座大闸进行整治与改造，形成长江——涨渡湖——七湖——陶家大湖——倒水河——举水河的大联通构局，形成江、湖、河之间的水循环，保护湿地生态，促进生物多样，使涨渡湖成为健康长江，还长江生命之网的典范。

参考文献
[1] 葛继稳 湿地资源及管理实证研究，科学出版社，2007年1月，北京
[2] 杨桂山、于秀波等 流域综合管理导论，科学出版社，2004年8月，北京
[3] 刘胜祥 植物资源学，武汉出版社，1994年8月，武汉
[4] 国家林业局 中国湿地保护行动计划，第1版，中国林业出版社，2000年9月
[5] 李黥湘 基于社区的涨渡湖流域综合管理，2005年6月，北京
[6] 国家林业局 湿地管理与研究方法，中国林业出版社，2001年7月，北京
[7] 陈家宽等 长江中下游湿地自然保护区，复旦大学出版社，2010年9月，上海
[8] 朱江、唐国朝等 重建江湖联系 保护涨渡湖湿地，人民长江，2005年11月号
[9] 黄茁等 促进江湖联系的闸口调度对策及影响区管理机制
[10] 雷阿林等 重建江（河）湖动态联系，修复水网生态环境
[11] 杨德德等 武汉涨渡湖湿地生物多样性研究和保护，广东科技出版社，2007年8月，广州
Primary Report of Lake Connection of Zhangdu Lake
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Abstract: Zhangdu Lake is a typical lake located on the north shore of the Central Yangtze River. In 1954, the built of Yangtze dyke disconnected the lake. Since 2005, to improve the wetland habitat and conserve the biodiversity, under the support of WWF, ditching work has been carried out to make connection of Zhangdu Lake and it has been a successful move in term of various management mechanism. This article has analyzed management mechanism of operation, examined the existing issues and provided recommendations for improvement.

Key words: Lake Wetland, Lake Connection, Operation Mechanism