# Dynamic Variation of Eco-Environment Quality of Reservoir Area after the Preliminary Stage Water Retaining

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***Abstract***
*Ecological environment of reservoir area has important strategic significance for the development of Chang-zhu-tan urban agglomeration, in order to protect ecosystem health and promote sustainable development of Reservoir area, the paper considers the aquatic ecosystems and terrestrial ecosystems to establish the comprehensive evaluation system, uses the fuzzy comprehensive evaluation method to evaluate the eco-environment quality from 2005 to 2014 and analyze the trends and tactors of reservoir area that water retaining of multipurpose hydraulic project in xiang river.*

*The result shows that:(1)the ecological environment has been moderate to severe disturbance from 2005 to 2014,the eigenvalues of eco-environment quality of reservoir area have in Ⅳ grade level around and the ecological environment quality is the worst in 2007; the ecological environment quality showing signs of improvement and most evaluation towards the positive direction from 2010 to 2014.(2)the runoff situation of reservoir area has been mainly affected by climatic fluctuations before water retaining of multipurpose hydraulic project in xiang river have run and the rainfall has positively correlated with annual runoff, annual mean flow and annual mean flow velocity, but the runoff situation of reservoir area has been mainly affected by water retaining of multipurpose hydraulic project in xiang river after it run, the second is climatic fluctuations; Water quality, sediment, water and land use is mainly affected by the upgrading of industrial structure adjustment and the effects of urbanization of reservoir area.*

**Keywords:** Changsha multipurpose hydraulic project in Xiang River, Reservoir area, Fuzzy comprehensive evaluation method, Eco-environment quality.

## Introduction

Xiang River is the largest river and the mother river of Hunan Province. Changsha, Xiangtan, Zhuzhou, Yueyang and Hengyang are major industrial cities located on two banks of Xiang River. 70% of medium-and-large-scale enterprises are located along Xiang River, thus forming an economic corridor

Since 2000, Xiang River has been faced with the prominent problem of seasonal water shortage, and inadequate water yield and low water level has been a frequent occurrence during the dry season. Especially, five continuous months of less rainfall after the latter half of July 2013 caused severe droughts and the water level during the dry season was lower than that of the 98% assurance rate by 1.2m. As a result, more than 86,000 people had difficult access to drinking water. Xiang River Changsha Multipurpose Hydraulic Project Phase II was completed in October 2012, succeeding in realizing impounding, navigation and bridge building. In 2013, it was put into use, making Changsha-Zhuzhou-Xiangtan becoming the unique reservoir area city agglomeration in China. As the comprehensive reform pilot area to building a "resource-economical and environment-friendly society" in China, Changsha-Zhuzhou-Xiangtan city agglomeration is confronted with both opportunities and challenges. Eco-environment quality has a close bearing on humans' survival and development, which lays the foundation for economic and social development and stability. Eco-environmental problems have become major barriers impeding regional sustainable development, economic stability and people's livelihood [1]. Thanks to Xiang River Changsha Multipurpose Hydraulic Project and positive human efforts, the eco-environment quality of the reservoir area has been significantly improved [2], which is of vital strategical importance to the development of Changsha-Zhuzhou-Xiangtan city agglomeration. In order to safeguard the health of the reservoir area's ecosystem health and promote sustainable development, it is imperative to learn the reservoir area's eco-environment status, changing trend and influencing factors.

In the current eco-environment research of the reservoir area, most scholars both at home and abroad analyze the eco-environment of the reservoir area simply from the perspective of the ecosystem. Foreign scholars mostly analyze the influence of building large-scale water conservancy facilities from the perspective of the river's aquatic ecosystem [3-4], while domestic scholars mostly evaluate and study the reservoir area's eco-environment quality by building an index system from the perspective of the terrestrial ecosystem [5-10]. There are few researches evaluating the reservoir area's eco-environment quality by combining the aquatic ecosystem and the terrestrial ecosystem, so it is impossible to comprehensively reflect the overall eco-environment quality of the reservoir area. The aquatic system and the terrestrial ecosystem of the terrestrial area are interconnected. As the entrance and the economic concentration area, the development of the Changsha-

Zhuzhou-Xiangtan city agglomeration influences the reservoir area's aquatic ecosystem, and the water environment quality can also influence the urbanization process. The two are an integrated whole.

In view of that, this paper established a comprehensive evaluation index system from the perspective of the aquatic ecosystem and the terrestrial ecosystem; uses the fuzzy comprehensive evaluation (FCE) to evaluate the eco-environment quality of Xiang River Changsha Multipurpose Hydraulic Project from 2005 to 2014; analyzes the changing trend and influencing factors of the reservoir area's eco-environment quality so as to further optimize Xiang River Changsha Multipurpose Hydraulic Project's regulation and storage plan and provide some theoretical references for the formulation of the environmental protection planning and measures for the Changshu-Zhuzhou-Xiangtan city agglomeration.

The reservoir area includes 14 districts and counties of the Changsha-Zhuzhou-Xiangtan city agglomeration, namely Yuelu District, Kaifu District, Tianxin District, Furong District, Yuhua District, Wangcheng County and Changsha County in Changsha City; Lusong District, Tianyuan District, Shifeng District and Zhuzhou County in Zhuzhou City; Yuetang District, Yuhu District and Xiangtan County in Xiangtan City. The area features the typical subtropical monsoon moist climate with the annual mean rainfall being 1,472.9mm. The rainfall is abundant, but is not proportional all the year around. The overall terrain is high in the east and the west and low in the center. The reservoir area is mostly alluvial basin area with the elevation ranging within 30~50m. The tributary drainage network is relatively developed. The major tributaries include Laodao River, Liuyang River, Longwanggang River, Jijiang River, Lianshui River, Juanshui River, Lvshui River, etc.

## Data sources and research methods

Data sources: Xiang River Changsha Multipurpose Hydraulic Project started construction in 2009. In 2012, it started impounding. In 2014, it was put into full use. Thus, this research chose 2005 to 2014 as the research period.

The research data come from Xiang River Changsha Multipurpose Hydraulic Project Environment Influence Report, Changsha Municipal Statistical Yearbook, Zhuzhou Municipal Statistical Yearbook, Xiangtan Municipal Yearbook, Hunan Provincial Statistical Yearbook, Hunan Provincial Water Resources Report and Hunan Provincial Rural Statistical Yearbook from 2006 to 2015, National Economy and Development Statistics Report of various counties, cities and districts, Environment Quality Status Report of Hunan Province and the Changsha-Zhuzhou-Xiangtan city agglomeration during the same period. The hydrological data come from the hydrological monitoring stations of Changsha, Zhuzhou and Xiangtan.

Research methods: Establishment of the evaluation index system, the comprehensive evaluation index system is built from the perspective of the aquatic system and the terrestrial system according to principles of scientificity, comprehensiveness, simplicity and hierarchy, complexity of data collection, research findings of previous scholars [5-10] and the reservoir area's practical situations. The evaluation index system consists of 25 indexes in eight aspects, namely water quality, runoff, bottom mud, aquatic biodiversity, local climate, water supply volume, water and soil loss and land utilization. (See Table 1)

Confirmation of the evaluation grades and the standard values: In terms of grading standards, the comprehensive pollution indexes, the nutritional state indexes and so on [11] are graded according to relevant literatures. The sediment indexes are graded according to the national standard of Environmental Quality Standards (GB15618-1995). Other indexes without the quantitative grading standards adopt the perennial value of the reservoir area (long-term annual mean value) as the grading bases. According to the practical situations, there are five grades, namely extremely beneficial, beneficial, no influence, slight influence, huge influence, which are represented by I, II, III, IV and V.

Confirmation of the evaluation index weight: There are objective and subjective valuing methods [12] to obtain the weight of various indexes. Then, adopt the average value of results got by each Method to confirm the final index comprehensive weight. (See Table 1)

Fuzzy membership calculation: Fuzzy comprehensive evaluation (FCE) [9] is a method built up based on principles of Fuzzy Mathematics. It is an analysis and evaluation method combining qualitative and quantitative methods, accurate and inaccurate methods. It divides the fuzzy boundary of things according to membership, and fully considers the contribution of every factor towards the comprehensive evaluation results. The contribution is distributed according to weight. Through fuzzy transformation and comprehensive calculation, the comprehensive membership can be obtained to confirm the eco-environment grade. The steps of the method are shown below:

①Build the evaluation factor set and the evaluation grade set; ②Build the membership function and the fuzzy matrix; ③Conduct the membership calculation; ④Work out the eigenvalue.

## Result and Analysis

According to the index weight of various levels worked out by the AHP and the entropy method, and FCE, the grade eigenvalue of the reservoir area's eco-environment quality and index layer (B) from 2005 to 2014 can be worked out. (See Table 2)

**Table 1**
**Eco-environment quality evaluation index system**

| Index layer (A) | Index layer (B) | Index layer (C) | Eco-environment quality influence grading | | | | |
|---|---|---|---|---|---|---|---|
| | | | Extremely beneficial | Beneficial | No influence | Slight influence | Huge influence |
| Reservoir's eco-environment quality | Water quality | Comprehensive pollution indexes | 0.2 | 0.4 | 0.7 | 1 | 2 |
| | | Nutrient substance sharing rate (%) | 10 | 20 | 40 | 60 | 80 |
| | | Organic poison sharing rate (%) | 5 | 10 | 15 | 30 | 50 |
| | | Heavy metal pollutant sharing rate (%) | 5 | 8 | 10 | 20 | 40 |
| | | Nutritional state indexes | 30 | 40 | 50 | 60 | 70 |
| | Runoff | Annual runoff ($10^8m^3$) | 800 | 600 | 500 | 300 | 250 |
| | | Annual mean water level (m) | 31 | 39 | 28 | 27 | 25 |
| | | Mean annual discharge ($m^3/s$) | 2500 | 2300 | 2000 | 1500 | 1000 |
| | | Mean annual flow velocity (m/s) | 0.65 | 0.5 | 0.45 | 0.4 | 0.3 |
| | | Annual sediment input volume ($10^4t$) | 100 | 200 | 300 | 600 | 1000 |
| | | Suitable ecological flow ($m^3/s$) | 3500 | 3000 | 2500 | 2000 | 1000 |
| | | Shipping capacity (tonnage) | 2000 | 1500 | 1000 | 500 | 300 |
| | Sediment | Hg (mg/kg) | 0.1 | 0.15 | 0.5 | 1 | 2 |
| | | Cd (mg/kg) | 0.15 | 0.2 | 0.6 | 1.5 | 2.5 |
| | \Aquatic biodiversity | Phytoplankton average biomass (mg/L) | 0.4 | 0.3 | 0.2 | 0.15 | 0.1 |
| | | Zooplankter average biomass (mg/L) | 0.5 | 0.4 | 0.25 | 0.2 | 0.15 |
| | Local climate | Annual rainfall ($10^8m^3$) | 550 | 500 | 400 | 350 | 300 |
| | | Annual mean temperature (℃) | 17 | 17.5 | 18.2 | 19 | 20 |
| | Water consumption | Total water consumption ($10^8m^3$) | 55 | 70 | 75 | 80 | 85 |
| | | Total industrial water consumption ($10^8m^3$) | 24 | 26 | 28 | 30 | 32 |
| | Water and soil loss | Water and soil loss area ($10^3hm^2$) | 15 | 40 | 120 | 160 | 200 |
| | | Vegetation coverage (%) | 50 | 45 | 35 | 25 | 20 |
| | Land use | Cultivated land ($10^3hm^2$) | 450 | 350 | 250 | 220 | 200 |
| | | Forestry area ($10^3hm^2$) | 70 | 65 | 60 | 55 | 50 |
| | | Landscape diversity index | 2.5 | 2 | 1.5 | 1 | 0.75 |

Note: The sediment data are the monitoring data of Xiawan Section of Xiang River in Zhuzhou; the annual runoff and the annual sediment input volume are the monitoring data of the Xiangtan Station; annual mean temperature is the monitoring data of Changsha.

**Table 2**
**Eco-environment quality evaluation weight**

| **Index layer（A）** | **Index layer（B）** | **Index layer（C）** | **Weight** | | |
|---|---|---|---|---|---|
| | | | **AHP-based weight** | **Entropy-method-based weight** | **Comprehensive weight** |
| Reservoir's eco-environment quality | Water quality | Comprehensive pollution indexes | 0.0503 | 0.0136 | 0.0320 |
| | | Nutrient substance sharing rate (%) | 0.0154 | 0.0047 | 0.0101 |
| | | Organic poison sharing rate (%) | 0.0429 | 0.0062 | 0.0245 |
| | | Heavy metal pollutant sharing rate (%) | 0.0721 | 0.0218 | 0.0469 |
| | | Nutritional state indexes | 0.0228 | 0.0012 | 0.0120 |
| | Runoff | Annual runoff ($10^8m^3$) | 0.0123 | 0.0100 | 0.0111 |
| | | Annual mean water level (m) | 0.0223 | 0.0003 | 0.0113 |
| | | Mean annual discharge ($m^3/s$) | 0.019 | 0.0094 | 0.0142 |
| | | Mean annual flow velocity (m/s) | 0.0451 | 0.0009 | 0.0230 |
| | | Annual sediment input volume ($10^4t$) | 0.0475 | 0.0312 | 0.0394 |
| | | Suitable ecological flow ($m^3/s$) | 0.0178 | 0.0299 | 0.0239 |
| | | Shipping capacity (tonnage) | 0.0322 | 0.0838 | 0.0580 |
| | Sediment | Hg (mg/kg) | 0.0271 | 0.4111 | 0.2191 |
| | | Cd (mg/kg) | 0.0814 | 0.3413 | 0.2113 |
| | \Aquatic biodiversity | Phytoplankton average biomass (mg/L) | 0.0464 | 0.0130 | 0.0297 |
| | | Zooplankter average biomass (mg/L) | 0.1391 | 0.0096 | 0.0743 |
| | Local climate | Annual rainfall ($10^8m^3$) | 0.0454 | 0.0061 | 0.0257 |
| | | Annual mean temperature (℃) | 0.0113 | 0.0002 | 0.0058 |
| | Water consumption | Total water consumption ($10^8m^3$) | 0.0331 | 0.0001 | 0.0166 |
| | | Total industrial water consumption ($10^8m^3$) | 0.0663 | 0.0011 | 0.0337 |
| | Water and soil loss | Water and soil loss area ($10^3hm^2$) | 0.0238 | 0.0041 | 0.0140 |
| | | Vegetation coverage (%) | 0.0715 | 0.0001 | 0.0358 |
| | Land use | Cultivated land ($10^3hm^2$) | 0.0163 | 0.0001 | 0.0082 |
| | | Forestry area ($10^3hm^2$) | 0.0295 | 0.0001 | 0.0148 |
| | | Landscape diversity index | 0.009 | 0.0001 | 0.0045 |

Note: The sediment data are the monitoring data of Xiawan Section of Xiang River in Zhuzhou; the annual runoff and the annual sediment input volume are the monitoring data of the Xiangtan Station; annual mean temperature is the monitoring data of Changsha.

**Table 3**
**Fuzzy comprehensive evaluation results of eco-environment quality from 2005 to 2014**

| **Year** | **2005** | **2006** | **2007** | **2008** | **2009** |
|---|---|---|---|---|---|
| Eco-environment quality | 3.8974 | 3.9888 | 4.1222 | 4.0290 | 4.0336 |
| Water quality | 4.1150 | 4.2353 | 3.9989 | 4.0025 | 3.9929 |
| Runoff | 3.2726 | 3.4715 | 3.9811 | 3.4836 | 3.1367 |
| Sediment | 5.0000 | 5.0000 | 5.0000 | 5.0000 | 5.0000 |
| Aquatic organism | 2.6380 | 2.9713 | 3.0094 | 3.2284 | 3.4284 |
| Local climate | 2.4691 | 2.6307 | 4.1007 | 3.2600 | 3.7446 |
| Water consumption | 2.3061 | 2.3168 | 2.7552 | 2.9453 | 3.3308 |
| Water and soil loss | 1.9709 | 1.9597 | 1.9256 | 1.8997 | 1.9725 |
| Land use | 2.5614 | 2.5823 | 2.5877 | 2.2896 | 2.6338 |
| | | | | | |
| Year | 2010 | 2011 | 2012 | 2013 | 2014 |
| Eco-environment quality | 3.8951 | 3.3033 | 2.9130 | 3.0707 | 2.9741 |
| Water quality | 3.9811 | 4.0127 | 3.7203 | 3.6544 | 3.6172 |
| Runoff | 2.5989 | 3.2476 | 2.0490 | 2.1081 | 2.1211 |
| Sediment | 5.0000 | 3.2693 | 3.3711 | 3.4729 | 3.4220 |
| Aquatic organism | 3.1332 | 2.8379 | 1.1713 | 2.2665 | 2.3428 |
| Local climate | 2.1305 | 4.2782 | 1.6810 | 3.7444 | 2.8321 |
| Water consumption | 3.9895 | 3.8280 | 4.5895 | 4.2097 | 3.3364 |
| Water and soil loss | 2.1463 | 2.1903 | 2.0461 | 1.9368 | 1.7813 |
| Land use | 2.6382 | 2.6644 | 2.6807 | 2.6880 | 2.6904 |

Eco-environment quality overall evaluation: Generally speaking, the reservoir area's eco-environment suffered medium and even severe influence. The eigenvalue of the eco-environment quality level of various years is between Level III and Level IV, and was greatly influenced by the sediment and water quality pollution.

In terms of trend, the eco-environment quality of the reservoir area from 2005 to 2009 was worsening. The eigenvalue of the aquatic organism and land use grade increased considerably. The sediment and the water quality were at a high pollution level. The eco-environment quality from 2010 to 2014 was improved slightly and developed in a favorable direction. In terms of the maximum value and the minimum value, the eco-environment quality was the worst in 2007. The eigenvalue of the water quality, runoff and local climate was around Level IV. The annual rainfall of local climate was just 1,201.63mm, thus influencing the reservoir area's runoff state and resulting in the decrease of indexes, including annual mean water level, annual mean runoff and navigation capability. In 2007, the reservoir area's water quality was relatively poor with the comprehensive pollution index being 2.7, which exceeded the Level V standard value (See Table 1) by 1.35 times. The sediment was faced with heavy metal pollution with Hg and Ca both exceeding the Level II standard in Soil Environment Quality Standards, of which Ca exceeded the standard amount by 275 times. In 2012, the eco-environment quality was the best and the reservoir area's annual rainfall was 1,792.4mm. On the one hand, the reservoir area's runoff state was greatly improved; on the other hand, the increase of the rainfall acted to dilute the water pollutants. The eigenvalue of the water quality grade was 3.7203.Compared with the water quality from 2005 to 2011, the water quality took a significant turnaround, of which Hg reached the Level II standard in Soil Environment Quality Standards.

Eco-environment quality evaluation based on various indexes: It can be seen from the water quality eigenvalue that the water quality was relatively poor from 2005 to 2011, which took a turn for good after 2012. (See Fig. 1) This was related not only to industrial structural upgrade and adjustment, but also to synchronous construction of Xiang River's water quality pollution treatment project during the construction period of Xiang River Changsha Multipurpose Hydraulic Project. The heavy metal pollutant sharing rate was consistent with the development trend of the water quality comprehensive pollution indexes, but showed a rebounding tendency in 2013 (See Fig. 1). This was related to the impounding and scheduling of Xiang River Changsha Multipurpose Hydraulic Project. After impounding, the water surface of the reservoir area widens and the water velocity slows down, which are not unfavorable for the diffusion, transfer and transportation of pollutants. With the decreasing capacity of the water environment, it might easily result in enrichment of the heavy metals in the reservoir area. From 2005 to 2014, the water nutritional state indexes showed a decreasing trend, and increased considerably in 2012. (See Fig. 2) This was related to the increasing concentration of nutrients caused by the discharge of nitrogen and phosphorus release of flora and fauna residual bodies in the initial impounding period of the reservoir area.

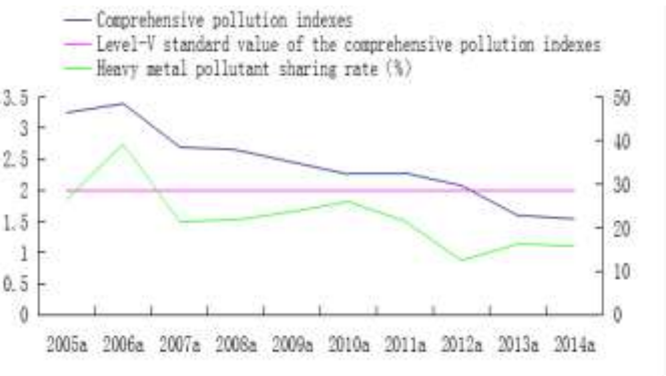


**Fig. 1: Change map of comprehensive pollution indexes of water quality and heavy metal pollution contribution rate**

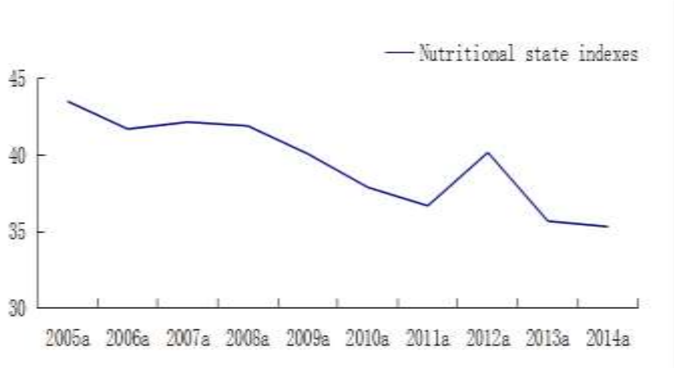


**Fig. 2: Change map of nutritional state indexes of reservoir area**

It can be seen from the runoff eigenvalue that the runoff was not stable and fluctuated greatly from 2005 to 2011; the runoff state tended to be stable from 2012 to 2014 and stayed around Level II. This suggested that the reservoir area's runoff was mainly influenced by the climate fluctuations before 2012. After 2012, the reservoir area was influenced by the Xiang River Changsha Multipurpose Hydraulic Project, turning from the natural run-off to the regulating runoff. In terms of the annual runoff, the fluctuation was significant. In 2011, the annual runoff reached the minimum level ($381.32\times10^8 m^3$). (See Fig. 3) The reason was that the annual rainfall of the year was the minimum (1,122.6mm). After the impounding of the Xiang River Changsha Multipurpose Hydraulic Project, the average water level rose considerably and maintained around 30m, which greatly increased the navigation power of Xiang River. The average flow rate slowed down considerably and the sediment input volume decreased gradually. (See Fig. 4) There were three reasons. First, the sand blocking effect of the large-scale reservoirs. Xiang River Changsha Comprehensive Hydraulic Project was the lowest stair of Xiang River main streams. The sediment was intercepted by the upper stairs one after another. Second, the water and soil loss treatment project and the slope protection hardening project on two banks of the Changsha-Zhuzhou-Xiangtan reservoir area. Third, the increase of the forest coverage. In terms of various research years, the sediment input volume was huge in 2010, reaching $685\times10^4$t. A major reason for it was that Changsha Multipurpose Hydraulic Project started construction in October 2009. The project construction increased the reservoir area's water and soil loss area. In the reservoir area, the water and soil loss area registered a year-on-year increase of 18.8%. On the other hand, influenced by the reservoir area's annual runoff, the annual runoff in 2010 reached a peak (See Fig. 3). By analyzing the correlation between the reservoir area's sediment input volume and annual runoff volume, the author worked out the correlation coefficient, which was 0.704 and passed the significance test of 0.05. This suggested that the annual runoff was related to the sediment input volume to some extent.

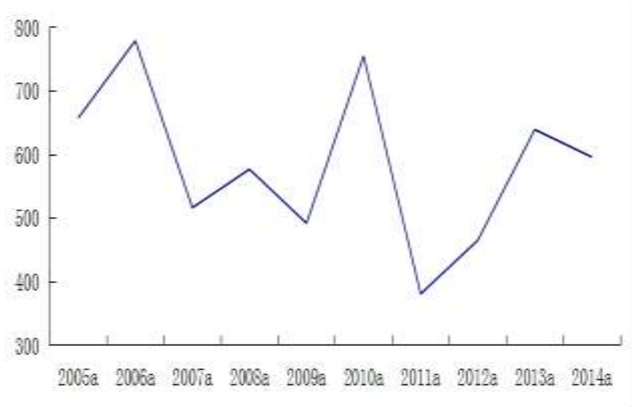


**Fig. 3: Change map of annual runoff of the reservoir area**

It can be seen that the sediment eigenvalue was all at Level-V before 2010 and that the heavy metal exceeded the standard seriously. In 2006, Ca exceeded the Level-II standard in Soil Environment Quality by 422 times. After 2011, the heavy metal content in the sediment decreased considerably. The major reason was the optimization and adjustment of the economic structure and the implementation of the heavy metal pollution treatment project. Despite of that, the heavy metal pollution was still serious in the reservoir area. Hunan Province is known as

"Hometown of Nonferrous Metals," and the industrial structure featured the heavy chemical industry. [13] During the upgrade and adjustment of traditional industries and the relocation and transformation of the old industrial bases, there were many historical environmental pollution problems left. It is a long way to address the heavy metal pollution.

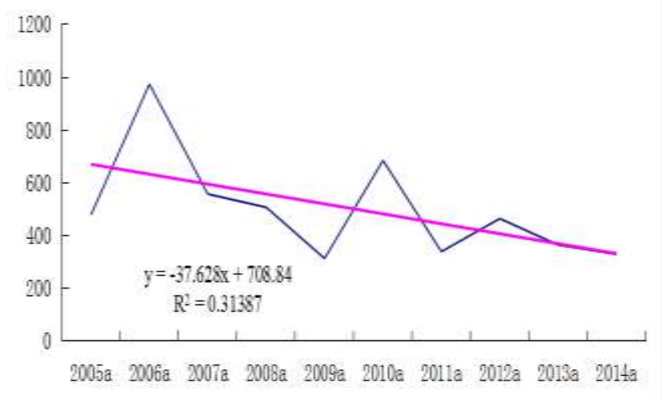


**Fig. 4: Linear regression of the sediment input of the reservoir area**

From the aquatic biological characteristics, it can be seen that the average aquatic biomass increased gradually. On the one hand, the water quality was improved significantly, so the heavy metal content decreased considerably; on the other hand, after the impounding of the reservoir area, the water flow slowed down, the sediment settled down and the substrate bio-environment covered by the gravel and the shoal will be gradually replaced by one covered by the sediment. The substrate bio-environment was significantly changed. At the same time, the submerging of the reservoir area resulted in the increasing dissolution amount of the organics and nutrient salts. Therefore, in the initial period of the reservoir area's impounding, the water's primary productivity will be increased significantly, so will the biomass.

In terms of the eigenvalue of the local climate, the change fluctuations are obvious. From Fig. 5, it can be seen that the average temperature of Changsha was on an upward trend, mainly affected by urbanization. During the urbanization process, due to increasing land uses, the impermeable specific surface area proportion increased by a large margin. The tropical island effect was significantly enhanced.

From the water consumption eigenvalue, it can be seen that value increased gradually from 2005 to 2012, but gradually decreased from 2013 to 2014. The water-use efficiency was increased considerably. The changing trend of the total industrial water consumption and the water consumption grade eigenvalue was consistent, and reached the maximum in 2012. (See Fig. 6) Industry is the major industrial water consumer following agriculture. To do a good work in industrial conservation is of vital importance to promote sustainable use of water resources.

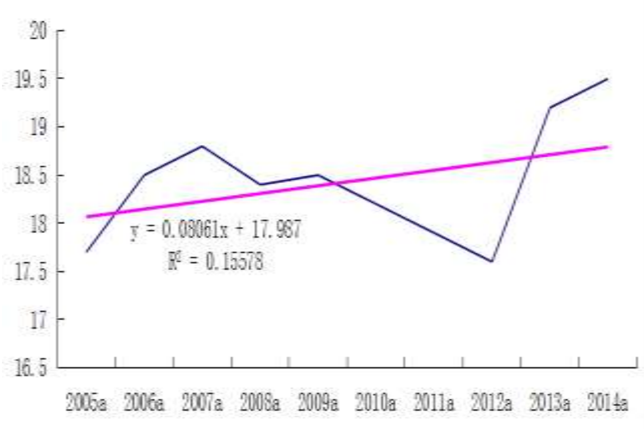


**Fig. 5: Linear regression of the annual mean temperature of Changsha City**

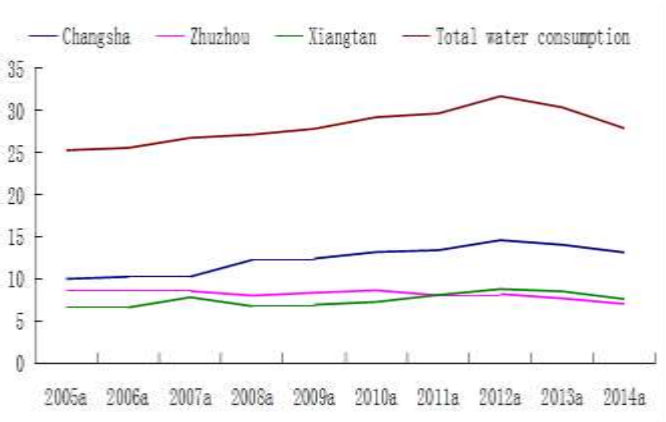


**Fig. 6: Change map of industrial water consumption**

From the water and soil loss eigenvalue, it can be seen that the eigenvalue of various changes did not change a lot. It was the beast in 2014, which was 1.7813. With the gradual increase of the reservoir area's forest coverage, the water and soil loss area was effectively controlled. However, due to the construction of Changsha Multipurpose Hydraulic Project from 2009 to 2012, water and soil loss was quite serious during the period.

The land use eigenvalue during the period differed not greatly from each other. All stayed at Level-II. In terms of the forest's total area, the total forest area of the reservoir area was on an increasing trend. Though the construction of Changsha Multipurpose Hydraulic Project, the reservoir inundation, the resettlement of inhabitants and the operation of the reservoir directly reduced the surrounding vegetation area, the reduced forest area accounted for 0.9‰ of the total forest area of the construction site (Wangcheng District). The decrease of the impounding volume accounted for 0.5‰ of the total of Wangcheng District. Therefore, the influence of the reservoir construction had a little influence on the reservoir's forest area, total impounding volume and forest coverage. At the same time, due to intensification of afforestation and reclamation efforts, the forest area was on the increase on an annual basis. Affected by urbanization factors, the urbanization area was expended annually, and the agricultural acreage decreased annually. Due to the influence of the impounding of Multipurpose Hydraulic Project, the water area increased, so did the landscape diversity index.

## Analysis of the influencing factors of the reservoir area's eco-environment

(1) Influence of the operation of Xiang River Changsha Multipurpose Hydraulic Project: After 2012, due to the operation of Xiang River Changsha Multipurpose Hydraulic Project, the water quality, sediment and aquatic biodiversity were affected by the reservoir's impounding and scheduling. The runoff of Xiang River Changsha Multipurpose Hydraulic Project turned from a natural one to a regulating one. As hydrological conditions changed, the water surface widened and the river's flow rate slowed down. (See Fig. 7) This was not favorable for the diffusion of pollutants, decreased the self-cleaning capacity and water environment capacity of the river. During the dry season (November to March), the monthly mean flow was more proportionally distributed compared with that before the operation of Xiang River Changsha Multipurpose Hydraulic Project (See Fig. 8), thus guaranteeing the industrial, agricultural and living water use and the normal navigation of 2,000-ton ships. In 2013, the heavy metal pollution of the reservoir area showed a rebounding tendency. (See Fig. 1) The slow-down of the flow rate was not favorable for the diffusion of pollutants and the discharge of sediment. With the enrichment of the sediment, the heavy metals deposited to the bottom of the reservoir. After a long time, the potential secondary pollution sources were formed. Under the influence of the reservoir's impounding and scheduling, Xiang River's natural hydrodynamic conditions were changed. Some heavy metal pollutants in the sediment re-entered the water body along with the sediment movement, thus causing the secondary pollution of the water quality. In the initial impounding period, the water flow rate slowed down, and the sediment deposited to the bottom, thus significantly changing the primary productivity of the water and increasing the aquatic bio-diversity.

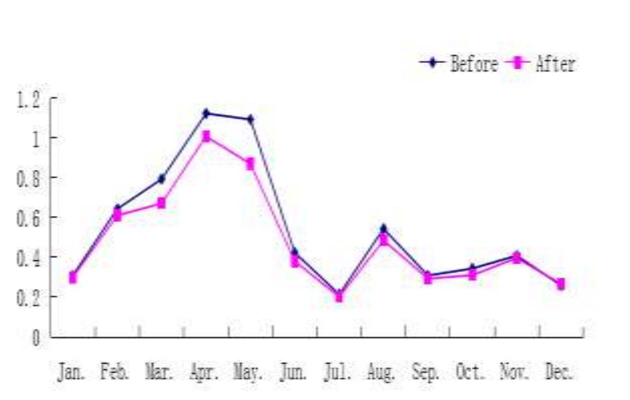


**Fig. 7: Comparison of the monthly mean flow rate of Xiangtan Station**


**Fig. 8: Comparison of the monthly mean flow volume of Xiangtan Station**

(2) Influence of industrial structural upgrade and adjustment: In recent years, the Changsha-Zhuzhou-Xiangtan city agglomeration has stuck to the main line of changing the economic development mode, upgrading and adjusting the industrial structure, transforming the traditional competitive industries, shutting down major polluting industrial enterprises, vigorously developing new-and high-tech industries, actively pushing forward the use of new energies, vigorously supporting the development of modern agriculture, building the riverside landscape belt and pushing the development of tourism. This is of vital positive significance to promote the reservoir's economic development, protect the water quality of Xiang River, reduce heavy metal pollution and increase the water-use efficiency. In order to push forward Xiang River's pollution treatment and prevention work, Hunan Province issued *The First Three-Year Action Plan for Pollution Treatment and Prevention of Hunan Xiang River*. With "blocking the pollution sources" as the major task, Zhuzhou finished 383 similar projects according to the implementation plan requirements in 2014. Among them, there were 41 heavy metal pollution treatment projects. In 2014, Zhuzhou closed and eliminated 98 polluting enterprises and production lines. One of them was a 100,000-ton traditional Pb refinement manufacturing technical system. By doing so, Zhuzhou succeeded in reading 18.295 tons of Pb, 1.644 tons of Ca and 0.025 tons of Ar annually. Besides, Zhuzhou Municipal Qingshuitang Old Industrial Basis is under relocation and transformation, which is of vital significance to reduce sources of heavy metal pollution.

(3) Influence of urbanization: Land use changes are one of the most typical processes of urbanization. The increase of the land use for urbanization will exert a great influence on the ecosystem structure, functions and mechanism of the surrounding environment, including bio-diversity, vegetation composition, soil organics, water quality and water cycling mechanism, etc. [14] The urbanization construction area of Changsha, Zhuzhou and Xiangtan increased from 155km$^2$, 85.6km$^2$ and 66.53km$^2$ in 2005 to 287.51km$^2$, 132.63km$^2$ and 79.2km$^2$ in 2014, respectively. The huge increase of urbanization construction area resulted

in changes of the underlying surface of the reservoir, thus impairing soil's water retaining ability, increasing the surface runoff and risks of draughts and floods in the reservoir area and enhancing the urban heat island effect. The environment pollution caused by urbanization include air pollution, water pollution, solid waste pollution, soil pollution, etc. [15] During the urbanization process, rural population pours into the urban area. The treatment and discharge of urban living sewage poses a great threat to the water quality of Xiang River. In 2007, the concentrated sewage treatment amount of Changsha was 320,000t/d. The urban sewage treatment rate was 45.42%. In 2009, Changsha launched the pollution interception project in the main urban area. In 2012, the concentrated sewage treatment amount increased to 1.05 million t/d, and the urban sewage treatment rate rose to 97.29%. Moderate urbanization is conducive to the improvement of the eco-environment. [15]

(4) Influence of climate fluctuations: Rainfall directly influenced the hydrological conditions of the reservoir area. Before the operation of Changsha Multipurpose Hydraulic Project, rainfall directly influenced indexes of the reservoir area, including annual runoff, flow and flow rate. Based on a correlation analysis of rainfall, and the annual runoff, annual mean flow and annual mean flow rate before and after the impounding of the reservoir area, it was found that the rainfall before the impounding was positively and significantly related to the above three indexes (0.01). It was apt to conclude that, before the operation of Changsha Multipurpose Hydraulic Project, the runoff of the reservoir area was mainly influenced by rainfall.

**Table 3**
**Correlation coefficients between annual runoff, annual mean flow, annual mean flow rate and annual rainfall**

| Indexes | Annual runoff | Annual mean flow | Annual mean flow |
|---|---|---|---|
| Correlation coefficient with the rainfall | 0.651* | 0.895** | 0.307 |
| Correlation coefficient with the rainfall | 0.942** | 0.932** | 0.95** |

Note: ** means correlation significance on the level of 0.01; * means correlation significance on the level of 0.05.

## Conclusion

1) From 2005 to 2009, the eco-environment quality of the research area was around Level-IV eigenvalue, suggesting that the eco-environment suffered medium and even severe influence. Among them, the eco-environment quality in 2007 was the worse. From 2010 to 2014, the eco-environment quality took a turn for good. The eco-environment quality in the reservoir area was most significantly influenced by the water quality and the sediment pollution.

2) Sub-item evaluation results suggested that most evaluation indexes developed in the favorable direction. However, the heavy metal pollution was still relatively severe. In particular, Ca exceeded the standard seriously. The operation of Changsha Multipurpose Hydraulic Project improved the hydraulic conditions of the reservoir area, improved the navigation power of Xiang River and guaranteed the water supply for the Changsha-Zhuzhou-Xiangtan city agglomeration. The water-use efficiency of the reservoir area was improved considerably, so was the forest coverage and landscape diversity index.

3) Before the operation of Changsha Multipurpose Hydraulic Project, the runoff situations of the reservoir area were mainly influenced by the climate fluctuations. The rainfall was significantly and positively related to the annual runoff, annual mean flow and annual flow rate. The water quality, sediment, water consumption and land use of the reservoir area were mainly affected by the upgrade and adjustment of the industrial structure and urbanization.

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