# Spatial-temporal Variation Characteristics of Water Quality in the Lower Reaches of the Nenjiang River

**Xiangzhe MENG[1], Jing WANG[1*], Yinglin XIE[1], Fei PENG[2], Chunsheng WEI[3], Xin TIAN[3], Lunwen WANG[3]**

1. Jilin Bureau of Hydrology and Water Resources (Jilin Water Environment Monitoring Center), Changchun 130022, China; 2. Information Center of Songliao Basin Committee of the Ministry of Water Resources, Changchun 130022, China; 3. Changchun Xinlicheng Reservoir Management Center, Changchun 130000, China

**Abstract** As an important river in the western part of Jilin Province, the lower reach of the Nenjiang River is an important wetland water source conservation area in Jilin Province. Within the watershed, it governs the Momoge Wetland, the Xianghai Wetland, and the Danjiang Wetland in Jilin Province. The main problem in the lower reaches of the Nenjiang River is the uneven distribution of water resources in time and space, and the intensification of land salinization. Zhenlai County and Da'an City in the Nenjiang River Basin have sufficient surface water resources, with surface water as the drinking water source. Baicheng City and Tongyu County have scarce surface water resources, and both use groundwater as their domestic water source. The main polluted section in the basin is the Xianghai Reservoir, and the annual water quality evaluation is Class V. However, the water quality of the Tao'er River, the main stream of the Nenjiang River, is significantly better than that of the Xianghai Reservoir. In order to better study the water environmental pollution situation in the Nenjiang River basin, monitoring data from five sections of non seasonal rivers in the basin from 2012 to 2021 were selected for studying water quality. This in-depth exploration of the water pollution status and river water quality change trends in the Nenjiang River basin is of great significance for future rural development, agricultural pattern transformation, and the promotion of water ecological civilization construction.

**Key words** Lower reaches of the Nenjiang River; Water quality; Spatial-temporal variation

**DOI** 10.19547/j.issn2152 -3940.2024.01.012

The Nenjiang River originates from the Ilehuli Mountain, northern foothills of the Greater Khingan Mountains and flows through Nenjiang, Qiqihar and other areas in Heilongjiang Province. It enters Jilin Province at Shijiazi in Dandai Township of Zhenlai County, passes through the boundaries of Taonan City and Taobei District, as well as four counties (cities, districts) at the boundaries of Zhenlai County and Da'an City. It turns eastward at the northwest of Hantun in Da'an County, and enters the Moon Bubble at the end. It is then injected into the Nenjiang River through the Haerjin Sluice of the Moon Bubble Reservoir. Within Jilin Province, the river is 279.7 km long and has a drainage area of 10 615 $km^2$. The section from Xinping to Zhenxi is a hilly area, with steep slopes and rapid flow, and the riverbed is composed of pebbles. The area below Zhenxi is a plain area, with well-developed river bends and many shoals. The riverbed is composed of small pebbles and fine sand, and the phenomenon of bank collapse is more severe. Below Taonan Town, there are many low-lying wetlands along the coast, with willow, reeds and wormwood growing in patches. The riverbed of the Nenjiang River and the Jiaoliu River leaks to recharge groundwater, and the runoff decreases downstream.

The Tao'er River originates from the Gaoyue Mountain in the Greater Khingan Mountains of Keyouqian Banner, and is a primary tributary of the Nenjiang River, consisting of ten small streams of varying sizes. It flows through Keyouqian Banner in Inner Mongolia and enters Jilin Province in Zhenxi of Taobei District, Baicheng City. It passes through four counties (cities, districts) of Taobei, Taonan, Zhenlai, and Da'an, and joins the Nenjiang River at Moon Lake. The river is 595 km long and has a drainage area of 33 100 $km^2$. The Tao'er River is 279 km long within Jilin Province, with a drainage basin area of 10 615 $km^2$. The Moon Lake is one of the larger lakes and reservoirs in Jilin Province, with a storage capacity of 1.199 2 billion $m^3$ and a reservoir area of 204 $km^2$. It creates favorable conditions for fish farming, irrigation, flood control, drought resistance, and other aspects in the basin.

The Jiaoliu River is a tributary of the Tao'er River, originating from the Laotou Mountain of Greater Khingan Mountains in the northwest of Tuquan County, Xing'an League, Inner Mongolia. It enters the territory of Taonan City of Jilin Province through Tuquan County and merges with the Tao'er River in the north of the city. The total length is 264 km, and the drainage area is 6 170 $km^2$. The river in Jilin Province is 124 km long, with a drainage area of 2 672 $km^2$. The upstream is a semi mountainous area, and the middle and lower reaches are hilly and plain areas. There is a tributary, the Najin River, flowing into the Jiaoliu River. There is a Qunchang Reservoir with a storage capacity of 59.6 million $m^3$ built on the Najin River[1].

The Huolin River originates from the northern foothills of Houfulehan Mountain in Zhalute Banner, Inner Mongolia Autonomous Region, and is a first-class tributary of the Nenjiang River. After flowing through Keyouzhong Banner of Inner Mongolia Autonomous Region, it enters Jilin Province and is divided into three

Received: November 16, 2023 Accepted: January 8, 2024
* Corresponding author.

streams in Xianghai Temple, Tongyu County: south, north, and middle (since the construction of Heishan Dam in the upper reaches of middle water in 1975, middle water has been blocked). The water in the north and south respectively crosses Shuanggang of the Pingqi Railway and Hujiadian Railway Bridge, and converge with the old river course of the Tao'er River in Taonan and Da'an City. It enters the Chagan Lake along the northern boundary of Qian'an County, then crosses the Liangliangdian Railway Bridge of Changbai Railway, and flows into the Nenjiang River through Kuli Bubble. The river is 590 km long and has a drainage area of 27 840 $km^2$. Among them, the river in Jilin Province is 308 km long and has a drainage area of 15 077 $km^2$, accounting for 44% of the total drainage area. After entering Jilin Province, the Huolin River flows through counties (cities) such as Tongyu County, Taonan City, Da'an City, Qian'an County, and Qianguo Banner. The Huolin River is an intermittent river with relatively low water volume in normal years and constant interruption in dry years[2]. Only in high water years is the water volume relatively abundant. For example, the Huolin River experienced a historic flood in 1998, and the maximum peak flow of the Baiyinhushuo Hydrological Station reached 4 320 $m^3/s$. Along both sides of the river, there was a vast ocean, causing many villages and farmland to be flooded, posing a serious threat to Tongyu County. In 1997, the section of the Huolin River in Jilin Province was continuously interrupted.

According to the Heidi Temple Hydrological Station in Zhenlai County, the flood period is in July and August, and the water level gradually decreases after September. After October, the flow rate decreases, it is the dry season until May of the following year. In dry years, there may be river drying or frozen bottom, with a minimum flow rate of 0. The highest flood level was 141.14 m (in 1954). Due to the breach of the Mudang Embankment in 1957, the flood spread and the discharge greatly decreased. The measured discharge was only 537 $m^3/s$, and the restored discharge was 2 300 $m^3/s$, with a maximum flow rate of 1.46 m/s. The maximum sediment concentration over the years is 5 280 $g/m^3$, with a minimum of approximately 0 and a maximum water temperature of 32 ℃. The freezing period is from late October to the end of March of the following year, with a maximum ice thickness of 1.13 m and an average ice thickness of 0.89 m over the years. The distribution of water systems in the Nenjiang River basin is shown in Fig.1.

Taobei District, Da'an City, Taonan City, Zhenlai County, Tongyu County in Baicheng City, and Qian'an County of Songyuan City are the main cities and counties that the Nenjiang River basin flows through Jilin Province, with a total of 117 townships and a total population of 2.273 9 million. Among them, agricultural people reaches 1.407 2 million, accounting for 61.9% of the total population. It is an area mainly composed of agricultural population. The entire watershed has approximately 6 413 $km^2$ of arable land, making it one of the large-scale commodity grain bases in China. The main economic crops and agricultural by-products are corn, rice, soybean, tobacco, reed, cotton, beef cattle, small grain, oilseed, and feed. According to statistics at the end of 1998, the total grain production in the entire watershed was 2.335 5 million t, and the total output value of agriculture, forestry, animal husbandry, and fishery was 4.958 billion yuan, of which the total output value of agriculture was 2.885 billion yuan. The industry within the watershed has also reached a certain scale, and there are 214 enterprises with a value of over 5 million yuan. The main industries include textile and clothing, transportation equipment, food and beverage, papermaking, medicine, cement, brewing, sugar production, *etc.* According to statistics at the end of 1998, the total industrial output value reached 4.678 billion yuan. The entire basin is rich in fishery resources, with lakes and reservoirs scattered everywhere, wetlands connected, and a total water surface of 1 432.756 $km^2$. Among them, there are 119 lakes and reservoirs with a breeding area of over 0.67 $km^2$, and the annual production of freshwater fish is 40 865 t[3].

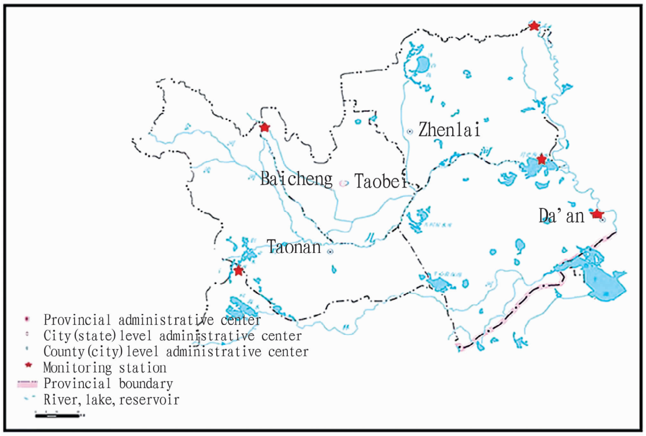


**Fig.1 River distribution in the lower reaches of the Nenjiang River**

## 1 Evaluation of water quality in the lower reaches of the Nenjiang River

**1.1 Section setting and water quality evaluation** Zhenxi, Xianghai Reservoir, Baisha Beach, Moon Lake Reservoir, and Da'an were selected as monitoring sections. The monitoring samples complied with the surface water detection method specified in the *Environmental Quality Standards for Surface Water* (GB 2828 - 2002). The data from Baicheng Branch of Jilin Water Environment Monitoring Center during 2013 - 2022 were selected for analysis.

**1.1.1** Implementation standards and methods for water quality monitoring. The monitoring samples followed the surface water detection method specified in the *Environmental Quality Standards for Surface Water* (GB 2828 - 2002). The specific detection methods and standards are shown in Table 1.

Using the fuzzy comprehensive evaluation method, the exceeding values of pollutants, water quality grading standards, and the contribution of pollutants to overall pollution are linked together. The specific steps are as follows:

(1) Establishing a set of evaluation objects $U = \{u_1, u_2, u_3, \cdots, u\}$. In this paper, $U = \{$DO, $BOD_5$, $COD_{Mn}$, COD, $NH_4$-N, TP, TN$\}$.

(2) Establishing water quality evaluation levels. In this paper, water quality evaluation level $L = \{I, II, III, IV, V\}$

(3) Establishing membership functions.

$$U(X) = \begin{cases} 1 & 0 \leqslant X \leqslant a_1 \\ \dfrac{a_2 - X}{a_2 - a_1} & a_1 < X \leqslant a_2 \\ 0 & X > a_2 \end{cases}$$

(4) Establishing fuzzy matrix. By using membership functions and measured values, the membership relationship of $i$ individual indicators to $j$ level of water quality is calculated, and a matrix is obtained.

$$R = \begin{bmatrix} r_{11} & r_{12} & \hat{} & r_{1j} \\ r_{21} & r_{22} & \hat{} & r_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{i2} & \hat{} & r_{ij} \end{bmatrix}$$

(5) Establishing weight matrix:

$A = \{a_1, a_2, a_3, \cdots, a_n\}$

(6) Calculating evaluation results:

$W = A \times R$

**Table 1 Main detection items and methods**

| Detection parameter | Standard code for testing method | Main instruments and equipment used and their numbers | Unit |
|---|---|---|---|
| DO | GB 7489 – 1987 | Brown acid burette | mg/L |
| $COD_{Mn}$ | GB 11892 – 1989 | Brown acid burette | mg/L |
| COD | HJ 828 – 2017 | Colorless acid burette | mg/L |
| $BOD_5$ | HJ 505 – 2009 | Brown acid burette | mg/L |
| $NH_4$-N | HJ 665 – 2013 | Continuous flow analyzer SAN + + (151910) | mg/L |
| TP | HJ 670 – 2013 | Continuous flow analyzer SAN + + (162113) | mg/L |
| TN | HJ 667 – 2013 | Continuous flow analyzer SAN + + (162113) | mg/L |

**1.1.2** Evaluation of water quality in the main stream of the Nenjiang River. Two monitoring sections have been set up in the main stream of the Nenjiang River. Among them, the water quality of the Baisha Beach was evaluated as Class IV from 2013 to 2018, and the water quality status has been evaluated as Class III since 2018. The water quality of Da'an section was evaluated as Class IV from 2013 to 2019, and was gradually improved to Class III. Ranked by the pollutant exceedance multiple from big to small, they were $NH_4$-N, $COD_{Mn}$, COD, $BOD_5$. The water quality evaluation results of two sections in the main stream of the Nenjiang River were both greater than or equal to Class III. Among them, $NH_4$-N exceeded the standard by 7.2 times in the Baisha Beach in 2009, followed by $COD_{Mn}$ exceeding the standard by 4 times. From then on, $NH_4$-N exceeded the standard by 3.7 times in 2013, followed by $COD_{Mn}$ exceeding the standard by 2.6 times. During this period, the COD and $BOD_5$ exceeded the standard by 1.5 and 1.6 times, respectively. The exceeding multiple of COD index has been maintained at around 1.5 times, and there was no significant change in the multiple of $BOD_5$ exceeding the standard. The water quality in river section of the Baisha Beach has been gradually improved since 2015, increasing from Class IV to Class III. The $NH_4$-N content in the Da'an section exceeded the standard to varying degrees from 2013 to 2017, while exceeding multiple of the $COD_{Mn}$ index at Da'an Station showed a decreasing trend year by year, and the exceeding degree of COD index remained unchanged. However, the concentration of pollutants significantly decreased after 2015, and the water quality was improved year by year.

**1.1.3** Water quality evaluation of the Tao'er River. Two sections were monitored to control the water quality of the Tao'er River, namely the Heidi Temple Reservoir and the Moon Lake Reservoir. The evaluation of the two sections revealed that the water quality of the rivers exceeded Class III, even reaching Class V in some years. The Moon Lake Reservoir had average water quality, with a lower exceeding multiple of pollutants. The main pollutants were ranked as follows: TN, TP, COD, $COD_{Mn}$, and $NH_4$-N. The water quality of the Moon Lake Reservoir in 2013 and 2015 was classified as Class V, while in other years it was classified as Class IV. TN exceeded the standard by 0.8 times, and COD exceeded the standard by 0.5 times, and $COD_{Mn}$ exceeded the standard by 0.2 times. Since 2017, the water quality has met the drinking water standards. The main pollutants at the Heidi Temple section were ranked as follows: COD, $NH_4$-N, $COD_{Mn}$. The water quality from 2014 to 2018 was Class IV, and then the water quality was upgraded to Class III. Since 2016, the $NH_4$-N and $COD_{Mn}$ indicators have been decreasing year by year. The improvement of water quality indicated an improvement in water environment quality.

**1.1.4** Xianghai Reservoir. Except for 2018, the water quality of the Xianghai Reservoir was classified as Class V and inferior Class V from 2013 to 2022. The pollutants was as follows according to exceeding multiple: F, COD, TN, $BOD_5$. In 2016, the exceeding multiples of F, COD, TN, and $BOD_5$ were 1.9, 0.9, 0.8, and 0.2, respectively. Due to the lack of stable surface runoff inflow, the pollutant sorting method exhibited by the Xianghai Reservoir was different from that of conventional lakes and reservoirs. Conventional lakes and reservoirs are usually dominated by TN and TP when participating in water quality evaluation. However, due to the relatively small inflow of non-point source pollution, F-compounds caused by the leaching of their own substrate and soil are the main pollutants. In addition, surrounding towns rely on groundwater as their source of living and production water. The water supply method is to supplement groundwater with surface water in wet years and supplement surface water with groundwater in dry years. A survey of soil moisture and rainfall data from 2013 to

2022 found that there are only two years with annual rainfall exceeding 200 mm. While groundwater replenishes surface water, it also carries out excess F elements from the local groundwater, some of which are dissolved in lakes and reservoirs, and some are deposited in the sediment of the Xianghai Reservoir, resulting in the water quality of the Xianghai Reservoir being classified as Class V or inferior Class V. In 2015, there was an increase in water quality levels. Investigation data found that the Ministry of Water Resources implemented a "water diversion project" in 2015, and introduced 20 000 $m^3$ of water into the Xianghai Reservoir, thereby diluting the concentration of pollutants and improving water quality.

**1.2 Changes of water quality trend in the lower reaches of the Nenjiang River** According to the analysis of water quality data from 2013 to 2022, the concentration of representative pollutants in the five sections has decreased. According to the analysis of water quality data from 2013 to 2022, it can be seen that the water quality of the five sections was developing in a positive direction, and the exceeding indicator of the Heidi Temple Station was mainly $NH_4$-N. From 2013 to 2022, the $NH_4$-N concentration significantly decreased, while the COD concentration significantly increased. The $NH_4$-N and $COD_{Mn}$ indexes at the monitoring section of the Baisha Beach showed a significant downward trend, while the COD index had no significant change trend. The $NH_4$-N and $COD_{Mn}$ indexes were the two main indicators that affected this section, and the significant decrease in their concentrations indicated that the water quality of the Baisha Beach section was improving year by year. The main pollutants of the Moon Lake Reservoir, TN and TP, have not shown significant changes over the past decade, while the concentrations of $NH_4$-N and $COD_{Mn}$ have been increasing year by year. There was no significant improvement trend in the water quality of this section. The main pollution control indicator of the Xianghai Reservoir, F compound, did not participate in trend analysis, so the significant decrease in $COD_{Mn}$, $NH_4$-N, and TP concentrations did not have a significant improvement effect on the Xianghai Reservoir.

## 2 Analysis of non-point source pollution in the lower reaches of the Nenjiang River

Sampling experiments were conducted based on the water quality sections set up in the Nenjiang River basin, and analysis was conducted on 5 monitoring points throughout 2018. Landsat 8 image data with a resolution of 60 m in May and September of 2018 in the Nenjiang River basin were selected again. Based on geometric correction and atmospheric correction, supervised classification was used to extract land use information within the area. According to the classification standard of the *Technical Specification for Ecological Environment Evaluation* (HJ 192 – 2015), the classification was conducted. Seven types of land cover, including urban land, cultivated land, grassland, wetland, forest land, bare land, and water body, were selected as the research objects. Data of land use types within five catchment units were obtained by combining DEM and water system distribution in the basin. The industry proportion information, per capita GDP, population density, and other data were all from the *Jilin Province Statistical Yearbook* and the *Baicheng City Statistical Yearbook* in 2017. The collected data were used for correlation analysis between water quality and land use status in the Yinma River basin by SPSS 17.0 software.

The extracted land use information map (Fig.2) was used for regional division, and the research area was divided into 5 catchment areas. From Fig.2, it can be seen that the urban area of B3 accounted for the largest proportion of the total area, which was between 39% and 53%. The cultivated land area accounted for 20% of the total proportion. The wetland area of B4 and B5 was relatively large, accounting for 30% – 35% of the total proportion. The cultivated land area of B2 and B1 accounted for about 30% of the total area, and the forest area of B2 accounted for about 15% – 17% of the total proportion. Overall, the cultivated land area in the five watersheds of B1 to B5 accounted for a significant proportion, while the bare land area remained around 8% – 10%. The proportion of vegetable land was relatively small, and there was a significant difference in the area proportion of land use types within the five watersheds.

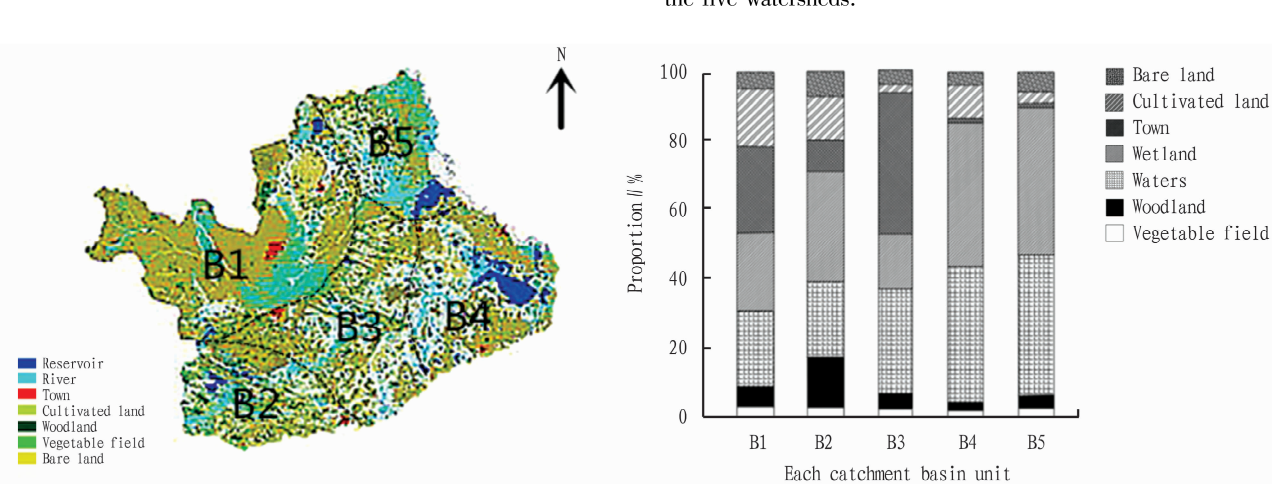


**Fig.2 Land use types and area ratio in the lower reaches of the Nenjiang River basin**

There is no correlation between land use area and COD, $BOD_5$, indicating a decrease in surface runoff and pollutant content due to reduced rainfall. TP is still positively correlated with cultivated land and vegetable fields, indicating that agricultural activities also have a significant impact during non flood seasons. There is a negative correlation between DO and water bodies, indicating that the decrease in rainfall and the slowing down of water flow rate lead to a decrease in the dynamic effect of DO entering the water body, resulting in a decrease in water oxygen content. $NH_4$-N is positively correlated with cultivated land, indicating that nitrogen nutrients are affected by cultivated land during both flood and non flood seasons (Table 2).

**Table 2 Correlation between land use pattern and water environment index in 2018**

| Land type | DO | $BOD_5$ | COD | TP | $NH_4$-N | pH | Chlorophyll |
|---|---|---|---|---|---|---|---|
| Cultivated land | 0.051 | −0.524 | −0.401 | 0.948 ** | 0.868 * | 0.182 | 0.145 |
| Urban land | −0.412 | −0.335 | −0.524 | 0.655 | −0.348 | 0.155 | −0.465 |
| Water body | −0.861 * | −0.612 | −0.447 | 0.622 | −0.14 | 0.166 | 0.047 |
| Grassland | −0.182 | −0.458 | −0.088 | 0.395 | −0.325 | −0.312 | 0.506 |
| Woodland | −0.511 | −0.478 | −0.355 | 0.567 | −0.546 | −0.234 | 0.248 |
| Vegetable field | −0.213 | −0.545 | −0.212 | 0.889 * | −0.054 | −0.258 | 0.287 |
| Bare land | 0.497 | 0.182 | 0.598 | 0.015 | 0.751 | 0.105 | 0.564 |

## 3 Analysis and management suggestions on water pollution in the lower reaches of the Nenjiang River

### 3.1 Evaluation of water pollution in the lower reaches of the Nenjiang River

TP, $NH_4$-N, and chlorophyll in the Nenjiang River basin are positively correlated with the proportion of the primary industry, negatively correlated with population density and the proportion of the tertiary industry, and positively correlated with the proportion of the secondary industry. The correlation between TP and the proportion of primary industry is most significant, which may be due to agricultural activities. Agricultural activities cause soil erosion, water becomes turbid, and phosphorus nutrients in the soil enter the water. The correlation between $NH_4$-N, chlorophyll and the proportion of the secondary industry is relatively high. This may be because that the industrial production increases the discharge of domestic sewage and industrial wastewater into water bodies, resulting in higher nutrient content in water bodies and an increase in the density of aquatic plants and phytoplankton. COD and DO are positively correlated with the proportion of the tertiary industry, and negatively correlated with the proportion of the secondary industry and per capita GDP.

### 3.2 Suggestions for water quality management in the lower reaches of the Nenjiang River

**3.2.1** Controlling the ecological water demand of river channels and reducing human influence on runoff control. Considering the climate and hydrological characteristics of the watershed, the development and utilization status of water resources, the types and functions of water ecosystem, the importance and sensitivity of protected objects, and the relative position of control nodes in the ecosystem, combined with important control sections[4], it should ensure the ecological base flow of rivers and the minimum ecological water level of lakes. Unnecessary dam construction should be reduced. When conducting environmental impact assessments, it should take into account the downstream ecological water demand caused by interception to avoid an increase in pollutant concentration.

**3.2.2** Reducing soil erosion and restoring wetland ecology. The western region of Jilin is a typical wind eroded area with severe soil erosion. The stripped rock and soil debris from wind erosion could increase the concentration of landmark pollutants in river water quality as rainwater washes into water bodies and lakes. Therefore, based on ensuring ecological flow, investment in water diversion projects could be increased and efforts could be made to restore soil salinization and alkalization, gradually restoring wetland functions.

**3.2.3** Taking effective measures and controlling non-point source pollution. It should implement scientific agricultural planting methods in agricultural areas, making full use of pesticides and fertilizers without waste. Strict pollution control measures for small farmers or enterprises should be implemented, and local legal supervision should be increased. It should raise public awareness, save water, and increase grain production. It should vigorously develop water-saving irrigation, control agricultural water consumption, reduce the loss of pollutants, and increase the clean water flow into rivers (reservoirs).

## References


[1] Hydrological Bureau of the Ministry of Water Resources. Water resources bulletin in 2019[Z]. 2020.

[2] DUAN LJ, WANG CY, MA JL, *et al*. The characteristics and countermeasures of non-point source pollution in Jilin Province[J]. Environmental Protection of Xinjiang, 2015, 37(2): 30 – 34.

[3] DING D, YANG B. Causes and countermeasures of agricultural non-point source pollution in Jilin Province[J]. Agriculture and Technology, 2014 (10): 26 – 27.

[4] ZHANG WL, JI HJ, KOLBE H, *et al*. Estimation of agricultural non-point source pollution in China and the alleviating strategies Ⅱ: Status of agricultural non-point source pollution and the alleviating strategies in European and American countries[J]. Scientia Agricultura Sinica, 2004, 37 (7): 1018 – 1025.