Spatiotemporal Variation Characteristics of Water Quality in the Yinma River

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Abstract As an important river in the central part of Jilin Province, the Yinma River plays a crucial role in the daily lives of the people in Jilin Province. In this paper, 15 cross sections were selected in the Yinma River basin. Based on the water quality monitoring data from 2012 to 2021, referring to the *Environmental Quality Standards for Surface Water* (GB 3838 - 2002) and historical monitoring data of the river, dissolved oxygen (DO), five-day biochemical oxygen demand (BOD_5), permanganate index (COD_{Mn}), chemical oxygen demand (COD), ammonia nitrogen (NH_4-N), total phosphorus (TP), and total nitrogen (TN) were determined as 7 evaluation indicators, and the water quality of 15 cross sections in the Yinma River basin was comprehensively evaluated. A characteristic analysis was conducted on the water quality of the Yinma River, and its pollution sources were identified. Based on the conclusions, constructive control measures were proposed.

Key words Yinma River; Water quality; Variation characteristics

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The Yinma River originates from the north of Desheng Village, Heyuan Town, Yitong Manchu Autonomous County, southeast of Laoye Ridge in the Hadaling Mountains of Jilin Province, and flows eastward. In local area, it is known as the Little Yellow River. From west to east, it flows into Panshi City, passes through Dadoumu, Jichang, Mingcheng, Yantai Mountain, Shanhe Town in Shuangyang District, Jinjia in Yongji County, Changlingzi in Shuangyang District, and Sijiazi in Jiutai District, enters Shitoukoumen Reservoir, and then passes through the Boni River, Xiyingcheng, the Yinma River in Jiutai, Daqingzuizi in Dehui City, and Dehui urban area, and becomes the boundary river between Nong'an County and the northern part of Dehui City. Finally, it flows into the Songhua River in Hongshi Village of Kaoshan Town and Jiangnan Town of Nong'an County[1].

The Yinma River basin covers an area of 18 247 km^2 (including the western Poluopao closed flow area), with a length of 386.8 km. Among them, its length is 60 km within Panshi City, 85 km as the boundary between Shuangyang District and Yongji County and Panshi City, 62 km within Jiutai District, and 102 km within Dehui City. The watershed area is 11 122.9 km^2, and the entire watershed is slightly inclined rectangular. The average slope of the river is 0.3 ‰.

It is a low mountain and hilly area above Yantongshan Town in Panshi City, with a valley width of over 1 km, a winding river channel, narrow and deep channels, and a riverbed of sand and pebbles. From Yantongshan Town to Shitoukoumen Reservoir in Jiutai District, there are gentle hills and tablelands along the river, and depressions and swamps are in the valley. The river channel is relatively curved, with sand or fine sand at the bottom. From the dam bottom of Shitoukoumen Reservoir to the mouth of the river, the river bends, and tablelands and plains are along the bank, with a wavy surface and developed gullies. There are swamps and aeolian sand dunes near the mouth of the river. At the mouth of the Yitong River, the meandering flow is shallow, and the riverbed is composed of fine sand and silt[1].

The upstream section is from the source to Yantongshan Town. There are undulating low mountains and hills on both sides of the river, shrubs and weeds overgrow. At both sides of the river, there is plain and valley over 1 km wide, mostly paddy fields. The upstream section of the river is curved, with narrow and deep channels. The riverbank is mostly sandy soil, steep and prone to collapse. The riverbed is composed of pebbles or fine sand, and floods rise and fall quickly. The river channel in forest areas is shallow, and the water flow is turbulent. The terrain is high in the southeast and low in the northwest, with many tributaries flowing in a north - south direction.

The midstream section is from Yantongshan Town to Shitoukoumen Reservoir, with flat low hills and tablelands along the bank. It is microwave shaped, with many depressions and swamps, and the river channel is curved and relatively flat. The riverbank is mostly composed of sand or sandy loam, and the riverbed is rich in sand or fine sand.

The downstream section is from Shitoukoumen to the mouth of the river. The tablelands on both sides of the river are widely distributed, and the edges of the tablelands are washed away by rainwater. The surface is wavy, especially at the mouth of the river, where there are swamps and wind blown sand dunes. The downstream flooding area is relatively large, especially in the estuarine areas, where the river channels are winding and there are many

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backflow phenomena. The two banks are composed of sandy loam soil, and the riverbed is composed of fine sand and silt, with a relatively gentle water flow.

The left bank of the Yinma River in Panshi City is connected to the Boli River in Bandenghe Village and the Yima River in Tianjia Village. This section of the Yinma River was once known as the "Little Yellow River". Every rainstorm, mountain torrents break out, resulting in water disasters[1].

The Yinma River is a first-level tributary of the Di'er Songhua River, and originates from the southeast side of Laoye Ridge in Hadaling Mountains of Yitong County. There is a confluence of the Yitong River at the left bank of Kaoshan Town in Nong'an County. After flowing into the southeast of Hongshilei Village, Kaoshan Town, Nong'an County, it injects into the Songhua River. The river is 386.80 km long and has a drainage area of 17 400 km^2 (including 9 300 km^2 of the Yitong River). The tributaries of the Yinma River basin with an area greater than 1 000 km^2 include the Shuangyang River, the Chalu River, the Wukai River, and the Yitong River[1].

The main stream of the Yinma River above Yantongshan Town in Panshi City is a low mountain and hilly area with dense shrubs. The valley is over 1 km wide and relatively flat, with many paddy fields on both sides. The river channel is curved, narrow and deep. The section from Yantongshan Town to Shitoukoumen Reservoir is characterized by gentle hills and tablelands along the river; from the dam bottom of Shitoukoumen Reservoir to the mouth of the river, the coastal areas are undulating tablelands and plains. The Yitong River is the largest tributary on the left bank of the Yinma River, originating from the north side of Qingdingzi Ridge in Hadaling Mountains of Yitong County. It flows through Changchun City and flows into the Yinma River in the east of Kaoshan Town, Nong'an County. The drainage area is 9 300 km^2, and the length of the river is 342.50 km. Above the Xinlicheng Reservoir, the two banks of the Yitong River are low mountain and hilly area with sparse growth of mixed forests. The Yinma River flows into Shitoukoumen Reservoir in the west of Wujia Village, Yongji County, with a drainage area of 1 100 km^2 and a length of 102.6 km. The average slope of the river is 1.6‰. The valley above Xingxingshao Reservoir in Chaluhe Town, Yongji County is narrow, with a relatively straight, narrow and deep channel. The riverbed is filled with sand and pebbles, and the water flow is fast. Below the Xingxingshao Reservoir, the valley gradually opens up, and the river channel bends. Runway is wide and shallow, and riverbed is fine sand. Distribution of water system in the Yinma River basin is shown in Fig. 1.

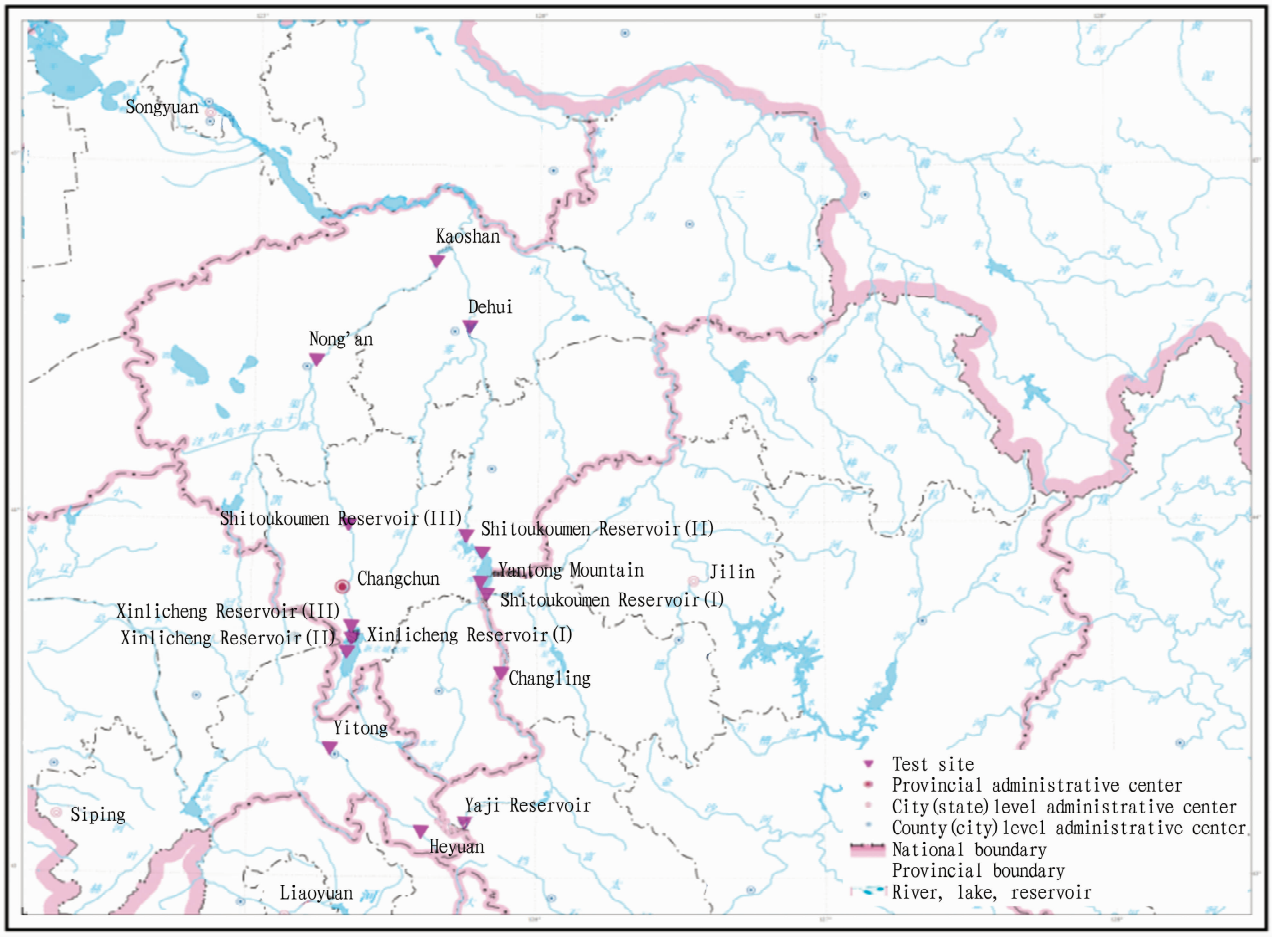

Fig. 1 Distribution of experimental sites in the Yinma River basin

The Yinmahe River basin is located in the central part of Jilin Province, with a terrain of high in the southeast and low in the northwest. From the perspective of terrain and landforms, it can be divided into the southeast low mountain and hilly area with black soil, and the central Songliao Plain mountain and plateau area with black soil. This basin belongs to the northern temperate continental monsoon climate zone. Its climate characteristics are: dry and windy in spring, hot and rainy in summer, clear and cool in autumn with large temperature differences, and cold and long in winter. The main source of its water vapor is the warm and humid airflow in the Bay of Bengal in the Pacific and Indian Oceans, with water vapor mainly flowing in the southwest and south – southwest directions. The average temperature throughout the year is generally between 2 and 6 ℃, and annual average sunshine hours is between 2 600 and 2 800 h, and frost-free period is between 120 and 140 d. The average annual precipitation at Changchun Station is 582.2 mm, with a rainfall of 451.2 mm from June to September, accounting for 77.5% of the annual precipitation. Annual average water surface evaporation is 1 719.2 mm (Φ 20); the average annual sunshine hours is 2 643.5 h; the average annual temperature is 4.9 ℃, with an extremely maximum temperature of 38 ℃ and an extremely minimum temperature of – 36.5 ℃ overthe years. The average annual wind speed is 4.3 m/s, and the maximum wind speed is 31 m/s over the years, and the maximum frozen soil depth is 169 cm.

The Yinma River basin is the economic center of Jilin Province, with the most developed industry and agriculture. It is located in the core area of the black soil belt in Northeast China, and is the main production area of rice, corn and other grain crops in Jilin Province. It is also an old industrial base in Northeast China and a major national commodity grain base. In terms of administrative divisions, it belongs to Chaoyang District, Kuancheng District, Nanguan District, Lvyuan District, Erdao District, Changchun Economic and Technological District, Jingyuetan Tourism Economy District, Changchun High-tech District, Shuangyang District, as well as Dehui City, Jiutai City, Nong'an County of Changchun City, and Yitong County of Siping City. The main cities and towns include Changchun City (including Chaoyang District, Kuancheng District, Nanguan District, Lvyuan District, Erdao District, Changchun Economic and Technological District, Jingyuetan Tourism Economy District, and Changchun High-tech District), Shuangyang District, Jiutai City, Dehui City, Nong'an County, and Yitong County.

In 2010, the total population of the Yinma River basin (including the Yitong River) was 8.501 1 million. The urban population was 6.108 7 million, and the rural population was 2.392 4 million, with the urbanization rate of 71.9%. In 2010, the gross domestic product (GDP) of the region was 286.487 billion yuan, accounting for 35.2% of the total GDP of Jilin Province. The added values of the primary, secondary, and tertiary industries were 30.229 billion, 135.25 billion, and 120.91 billion yuan, respectively. In 2010, the per capita GDP was 33 600 yuan/person, which was 1.56 times of the average level in Jilin Province. From this, it can be seen that the Yinma River basin plays an important role in the national economy of Jilin Province and plays a strategic role in driving the rapid development of economy and society in Jilin Province. Especially, Changchun, the provincial capital city located in the river basin, is a nationally renowned "forest city", "movie city", and "automobile city". It is one of the first batch of excellent tourist cities in China, and currently governs six districts and four cities and counties (Jiutai City, Yushu County, Nong'an County, and Dehui City), with a total area of 20 600 km^2.

The Yinma River basin, as one of the basins with dense old industrial bases in Jilin Province, has formed an industrial system with transportation equipment manufacturing as the main body and complete categories after years of development and construction. Among them, the famous FAW Group is the largest modern automobile research and production base with the most complete variety in China, with main products including sedans and medium-sized heavy-duty trucks. The annual production of automobiles accounts for one-fifth of the total production in China, and the output value of the automobile industry accounts for more than 50% of the total industrial output value in Changchun City. Changchun Bus Factory is a large research, production, and export base for railway and subway passenger cars in China. Changchun's industries such as buses, motorcycles, and tractors also hold a pivotal position in China. In addition, industries such as machinery, electronics, chemicals, metallurgy, and building materials also have a considerable foundation and broad development potential. According to statistics in recent years, the industrial added value in the Yinma River basin accounts for over 40% of the total industrial added value in Jilin Province; the added value of the tertiary industry accounts for more than 50% of the total added value of the tertiary industry in Jilin Province.

2 Water quality evaluation of the Yinma River basin

2.1 Water quality monitoring and evaluation methods

2.1.1 Implementation standards for water quality monitoring. The monitoring samples were tested according to the *Environmental Quality Standards for Surface Water* (GB 2828 – 2002). The specific detection methods and standards can be found in Table 1.

2.1.2 Water quality evaluation methods. 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 study, $U = \{DO, BOD_5, COD_{Mn}, COD, NH_4\text{-}N, TP, TN\}$.

(2) Establishing water quality evaluation level. The water quality evaluation level in this study $L = \{I, II, III, IV, V\}$.

(3) Establishing membership function.

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

(4) Establishing a fuzzy matrix. Using membership function

and measured values, the membership relationship of i individual indicators to the j^{th} level of water quality was determined, and the matrix was obtained.

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

(5) Establishing weight matrix.

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

(6) Calculating evaluation results.

$W = A \times R$

2.2 Water quality evaluation of the Yinma River basin 15 monitoring sections were selected for evaluation on the Yinma River (Table 2)[2]. Except for three sections of the Shitoukoumen Reservoir, in which water quality indicators were evaluated as Class III throughout the year, the other three water quality monitoring sections were classified as inferior Class V. According to the times of the pollutants exceeding the standard in the Changling section, the sequence from large to small was NH_4-N, TP, BOD_5, COD, and COD_{Mn}. In 2009, NH_4-N exceeded the standard by 9.9 times; TP exceeded the standard by 3.6 times, and BOD_5 exceeded the standard by 0.6 times. In 2013, NH_4-N exceeded the standard by 8.3 times; TP exceeded the standard by 2.2 times, and COD_{Mn} exceeded the standard by 0.1 times. By 2018, NH_4-N exceeded the standard by 6.7 times; TP exceeded the standard by 2.3 times, and COD exceeded the standard by 0.5 times. Overall, although the times of pollutants exceeding the standard has decreased, there was no slight change in pollutant indicators in different years, and overall control showed no significant change in the water quality of this section[3]. The perennial water quality category of the Latapao section was also classified as inferior Class V. According to the times of pollutants exceeding the standard, the sequence from large to small was NH_4-N, BOD_5, COD, and COD_{Mn}, respectively. In 2009, NH_4-N exceeded the standard by 5.8 times; BOD_5 exceeded the standard by 0.8 times, and COD exceeded the standard by 0.1 times. In 2013, NH_4-N exceeded the standard by 0.5 times; BOD_5 exceeded the standard by 0.7 times, and COD exceeded the standard by 0.2 times in the Changling section. By 2018, NH_4-N exceeded the standard by 0.5 times; BOD_5 exceeded the standard by 0.6 times, and COD exceeded the standard by exceeded 0.5 times. This section indicated that the pollution was particularly stable. It indicated that the surrounding conditions of the watershed were stable, and the concentration of pollutants has been reduced, and the water quality was moving in a positive direction. The Dehui section is a control section where the Yinma River flows into the Second Songhua River. Its perennial water quality control category is inferior Class V. According to the times of pollutants exceeding the standard, the sequence from large to small was NH_4-N, BOD_5, COD, and TP. When analyzing this section, it was found that although the source of pollutants was stable, the NH_4-N index showed a turning point where it exceeded the standard by 7.5 times in 2009, decreased to

Table 1 Main detection items and application methods

No.	Detection parameter	Code for testing methods and standards	Main instruments and equipment used and their numbers	Unit
1	DO	GB 7489 – 1987	Brown acid burette	mg/L
2	COD_{Mn}	GB 11892 – 1989	Brown acid burette	mg/L
3	COD	HJ 828 – 2017	Colorless acid burette	mg/L
4	BOD_5	HJ 505 – 2009	Brown acid burette	mg/L
5	NH_4-N	HJ 665 – 2013	Continuous flow analyzer SAN + + (151910)	mg/L
6	TP	HJ 670 – 2013	Continuous flow analyzer SAN + + (162113)	mg/L
7	TN	HJ 667 – 2013	Continuous flow analyzer SAN + + (162113)	mg/L

Table 2 Section setting of the Yinma River basin

No.	Water system	River name	Section	Code
1	The second Songhua River	Yinma River	Changling	C1
2	The second Songhua River	Yinma River	Shitoukoumen Reservior (I)	C2
3	The second Songhua River	Yinma River	Shitoukoumen Reservior (II)	C3
4	The second Songhua River	Yinma River	Shitoukoumen Reservior (III)	C4
5	The second Songhua River	Yinma River	Latapao	C5
6	The second Songhua River	Yinma River	Dehui	C6
7	The second Songhua River	Yitong River	Kaoshantun	C7
8	The second Songhua River	Yitong River	Taipingchi Reservoir	C8
9	The second Songhua River	Yitong River	Yitong	C9
10	The second Songhua River	Yitong River	Xinlicheng Reservoir (I)	C10
11	The second Songhua River	Yitong River	Xinlicheng Reservoir (II)	C11
12	The second Songhua River	Yitong River	Xinlicheng Reservoir (III)	C12
13	The second Songhua River	Yitong River	Changchun	C13
14	The second Songhua River	Yitong River	Nong'an	C14
15	The second Songhua River	Yitong River	Kaoshan	C15

1.7 times in 2015, and increased to 5.1 times during the evaluation in 2018. During this period, the water quality category evaluation was still inferior Class V. Except for the drinking water source control section, water quality of the other three sections was stably controlled in inferior Class V. It was found that most of the exceeding times were slowly decreasing year by year, indicating that the water quality of the Yinma River was improving year by year.

Monitoring results of water quality in the Yinma River basin showed that Class III water quality of monitoring sections accounted for 48%; Class IV water quality accounted for 5%, and inferior Class V water quality accounted for 47% of the total evaluation. The Yinma River and the Yitong River were severely polluted by industrial and urban domestic wastewater as well as agricultural non-point source pollution in Changchun City. The Shitoukoumen Reservoir and Xinlicheng Reservoir are the water supply sources for Changchun City. Most of the water from the upstream of the Yinma River and Yitong River is intercepted. In addition, the Yinma River basin has less rainfall, and natural runoff is small, and the self purification ability of the river is small. Pollutants cannot be effectively diluted and degraded, resulting in the lower reaches of the Yinma River and Yitong River having inferior Class V water quality, and the water quality does not meet the standard.

3 Conclusions

Nearly half of the rivers in the Yinma River basin have been severely polluted. Although the pollutant indicators have shown a significant decline, and the water quality of the rivers is constantly improving, the water environment in the Yinma River basin is still not optimistic.

Except for Shitoukoumen Reservoir and Changling, the water quality in Latapao and Dehui sections has always been inferior Class V. The main exceeding items of Latapao section were NH_4-N, DO, and COD, with NH_4-N exceeding the standard by 5.8 times. The main exceeding items of the Dehui section were NH_4-N, BOD_5, and TP. In the 9 selected sections of the Yitong River, except for the water quality in Xinlicheng Reservoir section being Class III, all other river sections in the project area had the water quality of inferior Class V. The main pollutants exceeding the standard included COD, COD_{Mn}, NH_4-N, COD_5, and DO. Among them, annual NH_4-N, COD, and TP in Kaoshan, Nong'an, and Yitong exceeded the standard.

The water quality in the Yinma River basin is improving year by year. However, as the Yinma River basin is a major grain crop planting area in Jilin Province, it is mainly affected by non-point source pollution, which has a significant seasonal impact. Therefore, it is necessary to increase the development of agricultural green industries and strengthen the construction of ideological awareness in order to gradually restore good eco-environment.

4 Suggestions

The tributaries of the Yinma River basin and some urban areas are heavily polluted. Among them, the water quality of the Yitong River, the Yinma River, and the bridge section of Yangjiaweizi, Changchun City is inferior Class V, with severe pollution. Agricultural pollution is an important factor affecting water quality, such as pollution from pesticides, fertilizers, rural wastewater, waste, and livestock farming. The large amount of pesticides and fertilizers used in the Yinma River basin and low utilization rate lead to a large amount of residues entering the surface and groundwater. Due to the lack of appropriate pollution treatment equipment in many livestock farms, a large amount of livestock manure directly pollutes the environment. The capacity for water environment supervision and risk prevention is weak. Due to various limitations, the environmental monitoring institutions in the region are lagging behind, and it is necessary to improve the assessment, early warning, and emergency system of water resource.

Suggestions: ① increasing control of non-point source pollution and promoting the sound legal system; ② accelerating the process of agricultural technology and developing green agriculture; ③ special governance in key areas.

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