Research on spatial-temporal distribution characteristics of main pollutants of the rivers in the Linyi Development Zone

Chao Liu, Binjie Qian, Liyuan Wang and Qun Miao

ABSTRACT

The pollution issues with urban rivers is one of the key factors affecting the urban ecological environment, and water pollution control has become the top task for urban ecological construction. The first step of controlling water environment pollution is to have an objective knowledge of the water quality. This research selects the rivers in the Linyi Development Zone as the subject and analyzes the major pollution factors and the spatial-temporal distribution characteristics of the main pollutants in the river system based on routine monitoring data of the river system in the zone from August 2014 to May 2017, and also accurately judges the variation trend of the water quality with the time through the Spearman rank relational coefficient. The research result shows that NH3-N, TP, CODCr, CODMn, BOD5 are the main pollution factors. Between 2014 and 2017, the overall water quality variation trend of the river system in the development zone is very significant, and the water quality variation basically remains stable. The water quality variation and major pollution sources of the rivers in the development zone are judged, providing an important basis for the water ecology construction of the development zone.

Key words | Linyi Development Zone, pollution factors, river system, spatial-temporal distribution, Spearman rank relational coefficient

INTRODUCTION

Human beings have tended to live by the water from time immemorial. The rivers breed cities and urban civilization. The development of cities is closely linked with the rivers. With the rapid development of urban construction, the pollution issue of urban rivers has become increasingly prominent, affecting the ecology environment, harming human health, and hindering the further development of cities. Therefore, urban river pollution control is the top task of current ecology construction. As for river pollution control, the water quality evaluation of the water body and spatial-temporal distribution characteristics of the main pollutants are the important basis (Deng 2017).

The urban river is a complex water environment system. To control the urban water environment pollution issue, it is imperative to have an objective knowledge of the situation of the water environment in the zone (Loucks et al. 2005). Due to limited time, difficulty of data acquisition, etc. of previous research, a majority of the research only pays attention to one or several sections of a river or only analyzes the river water quality over a year, and it is difficult to objectively and accurately reflect the river water quality with the absence of data with long enough time scales and wider coverage (Liu et al. 2011; Xu et al. 2012; Seth et al. 2016; Li et al. 2017; Şener et al. 2017; Xia et al. 2017). This research selects seven representative rivers of the river system in the Linyi Development Zone as the research subject, on the basis of the routine monitoring data of the water quality of 12 common sections of the rivers, finds the main pollution factors affecting the
river water quality in the development zone through mathematical statistics methods, analyzes the spatial-temporal distribution characteristics of the rivers in the development zone between 2014 and 2017, and analyzes the water quality variation trend using the Spearman rank relational coefficient method (Xin et al. 2015). It can objectively recognize the main pollution sources and water quality variation trend of the rivers in the development zone through the analysis, providing an important scientific basis for subsequent water environment governance and pollution control in the development zone.

MATERIALS AND METHODS

Research zone

The Linyi Development Zone is located in the east longitude of 118°23′ to 118°32′, and the north latitude of 34°53′ to 35°02′. The control area in the plan is 223 km². The water system development in the development zone is distributed in a veined shape, with mean annual precipitation of 862.5 mm and mean annual runoff depth of 329.9 mm within the zone. The total volume of the river water resources is sufficient, but the spatial distribution is not uniform, and the required water volume for ecology is not sufficient, especially the required water volume for rivers in the non-flood seasons. The major rivers in the development zone include Ligong River, Jiebai River, Pengbai River, Yubai River, Xiaobudong River, Xiaodungou River, and Huangbai River. The rivers constitute an interconnected system. As the major water ecological environment in the development zone, its governance has important significance for the ecological protection of the zone. The basic situation of the river water system in the development zone is shown in Table 1.

Water quality monitoring data

Monitoring sections

This research selects a total of 12 common monitoring sections set on the major rivers in the zone, such as Ligong River, Jiebai River, Pengbai River, Yubai River, Huangbai River, Xiaobudong River, and Xiaodungou River. From the spatial distribution, the monitoring sections cover the entire development zone along the inland river system, and are evenly distributed in the upstream, midstream, and downstream. The monitoring section positions are shown in Figure 1.
Monitoring time frames and water quality parameters

The monitoring sections mainly target 21 basic items in the Environmental Quality Standard for Surface Water (GB3838-2002), including pH, DO, COD$_{Cr}$, BOD$_5$, NH$_3$-N, TP, COD$_{Mn}$, petroleum class, volatile phenol, fluoride, cyanide, sulfide, arsenic, lead, cadmium, copper, zinc, hexavalent chromium, mercury, selenium, and anionic surfactants. The monitoring frequency of the research is once a month.

This research obtains routine water quality monitoring data for each section for the consecutive 34 months from August 2014 to May 2017 for a total of 408 groups. Among them, the monitoring factor of volatile phenols lacks the data of individual months. In the analysis, the monthly data are generated using the linear interpolation method of two sampling times. For some water quality parameters below the detection limit, the method detection limit is used as the parameter analysis data.

Evaluation index selection and evaluation standards

Selection of evaluation index

In order to comprehensively reflect the situation of water pollution in the zone, the index selection must be comprehensive and representative (Novotny 1994; Chapra 2008). This study combines surveys of local pollution sources, and refers to domestic and provincial river pollution characteristics of the same type of cities, selects a total of 11 water quality parameters, such as pH, DO, COD$_{Cr}$, BOD$_5$, NH$_3$-N, TP, COD$_{Mn}$, volatile phenol, fluoride, cyanide, and sulfide as the evaluation index.

Evaluation standards

According to the Environmental Quality Standard for Surface Water (GB3838-2002), based on surface water environmental function classification and protection objectives, the items and limit values that shall be controlled for the water environment quality are shown in Table 2. According to the functions of the water area of the development zone and the requirements of the local water environment, the water environment quality of seven major rivers in the development zone will be subject to category IV standards.

Research method

The water environment is a complex system, and the water quality monitoring value is also affected by many factors, often showing greater volatility (Ayers & Westcot 1985; Wang 2006). Because the water environment itself has a large degree of ambiguity (Zhou & Gao 2008), in order to accurately determine the trend of the water quality over time, the principle of mathematical statistics is generally used for trend checks and analysis. Through the analysis of the trend of water quality changes, it is possible to determine whether the currently implemented water pollution control measures are appropriate, and it can also provide an important basis for the effective management and control measures of river water quality in the future (Chang 2008).

The Spearman rank relational coefficient method is the most commonly used method to test whether the water environmental quality pollution trend is statistically significant (Alberto et al. 2001; Singh et al. 2004; Shrestha & Kazama 2007). Using Daniel's trend test, the Spearman rank correlation coefficient can be used to determine whether the trend of water quality in the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
<th>Class V</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6–9 (dimensionless)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td>7.5</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>COD$_{Mn}$</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>COD$_{Cr}$</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>BOD$_5$</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>NH$_3$-N</td>
<td>0.15</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>TP</td>
<td>0.02</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Fluoride</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Volatile phenol</td>
<td>0.002</td>
<td>0.002</td>
<td>0.005</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Sulfide</td>
<td>0.05</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>
monitoring period tends to get better, worse, or change slightly (Tu 2011). The method is simple and intuitive, with high accuracy, and is suitable for this study. The Spearman rank relational coefficient is calculated as follows:

$$ r_s = 1 - \frac{6}{N^2-N} \sum_{i=1}^{n} d_i^2 $$

$$ d_i = X_i - Y_i $$

where $r_s$: the Spearman rank correlation coefficient; $N$: sample size; $d_i$: the difference between the variable $X_i$ and the variable $Y_i$; $X_i$: the numbers sorted from lowest to highest of the cycle $i$ to cycle $n$ based on the concentration values; $Y_i$: the numbers sorted chronologically.

The selected significance levels are 0.05 and 0.01. For the critical value of the Spearman rank relational coefficient $W_p$, when $|r_s| > W_p$, this indicates that the water quality variance has obvious significance, and if $r_s < 0$ at this time, this indicates that the water quality tends to get better, and if $r_s > 0$, this indicates that the water quality tends to get worse. When $|r_s| < W_p$, this indicates that the variation trend has no obvious significance, and the water quality variation tends to remain stable.

## RESULTS AND DISCUSSION

### Recognition of main pollution factors of the water system in the development zone

In order to better analyze the spatial-temporal distribution characteristics of the river system in the development zone, the main pollution factors of the inland river system need to be recognized. This research carries out the statistical analysis of the routine monitoring data of the section water quality of the consecutive 34 months from August 2014 to May 2017 through the mathematical statistics method, and recognizes the main pollution factors of the inland river system in the development zone. The statistics results are shown in Table 3.

The results show that all of the pH value, DO, and sulfide of all samples in this research meet the category IV standard for surface water, and fail to exceed the standard. COD$_{Cr}$ of 49.3% samples is inferior to that specified in the category IV standard for surface water (30 mg/L), with the maximum over-standard multiples of 7.63. COD$_{Mn}$ of 41.9% samples exceeds that specified in the category IV standard for surface water (10 mg/L), with the maximum over-standard multiples of 7.63. BOD$_5$ of 64.5% samples exceeds that specified in the category IV standard for surface water (6 mg/L), with the maximum over-standard

### Table 3 | The statistics of the water quality indexes of the inland water system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of sample</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Mean</th>
<th>Over standard rate (%)</th>
<th>Maximum exceeding standard multiple</th>
<th>Average exceeding standard multiple</th>
<th>Standard deviation (SD)</th>
<th>Coefficient of variation (CV) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>408</td>
<td>8.95</td>
<td>6.0</td>
<td>7.07</td>
<td>0</td>
<td>/</td>
<td>/</td>
<td>0.46</td>
<td>6.6</td>
</tr>
<tr>
<td>DO</td>
<td>408</td>
<td>8.7</td>
<td>3.4</td>
<td>6.0</td>
<td>0</td>
<td>/</td>
<td>/</td>
<td>0.77</td>
<td>12.8</td>
</tr>
<tr>
<td>COD$_{Mn}$</td>
<td>408</td>
<td>86.3</td>
<td>0.003</td>
<td>10.6</td>
<td>41.9</td>
<td>7.63</td>
<td>0.06</td>
<td>6.97</td>
<td>65.8</td>
</tr>
<tr>
<td>COD$_{Cr}$</td>
<td>408</td>
<td>299</td>
<td>12</td>
<td>36</td>
<td>49.3</td>
<td>8.97</td>
<td>0.20</td>
<td>23.79</td>
<td>66.1</td>
</tr>
<tr>
<td>BOD$_5$</td>
<td>408</td>
<td>49.2</td>
<td>1.6</td>
<td>8.8</td>
<td>64.5</td>
<td>7.2</td>
<td>0.44</td>
<td>5.64</td>
<td>65.0</td>
</tr>
<tr>
<td>NH$_3$-N</td>
<td>408</td>
<td>29.9</td>
<td>0.1</td>
<td>5.1</td>
<td>78.2</td>
<td>18.9</td>
<td>2.38</td>
<td>4.67</td>
<td>91.9</td>
</tr>
<tr>
<td>TP</td>
<td>408</td>
<td>9.8</td>
<td>0.11</td>
<td>0.96</td>
<td>91.9</td>
<td>31.7</td>
<td>2.21</td>
<td>0.93</td>
<td>97.0</td>
</tr>
<tr>
<td>Fluoride (F$^-$)</td>
<td>408</td>
<td>7.31</td>
<td>0.21</td>
<td>1.03</td>
<td>9.8</td>
<td>3.87</td>
<td>-0.32</td>
<td>0.56</td>
<td>54.6</td>
</tr>
<tr>
<td>Volatile phenol</td>
<td>408</td>
<td>0.05</td>
<td>0.0007</td>
<td>0.003</td>
<td>0.49</td>
<td>4.13</td>
<td>-0.67</td>
<td>0.003</td>
<td>87.7</td>
</tr>
<tr>
<td>Petroleum</td>
<td>408</td>
<td>0.71</td>
<td>0.005</td>
<td>0.06</td>
<td>0.25</td>
<td>0.42</td>
<td>-0.8</td>
<td>0.05</td>
<td>83.6</td>
</tr>
<tr>
<td>Sulfide</td>
<td>408</td>
<td>0.087</td>
<td>0.0025</td>
<td>0.018</td>
<td>0</td>
<td>-0.83</td>
<td>-0.96</td>
<td>0.01</td>
<td>74.5</td>
</tr>
</tbody>
</table>
The spatial-temporal distribution characteristics of main pollutants of rivers

Temporal distribution characteristics

To research the trend of the main pollutants in each monitoring section of the river system in the development zone, combined with the recognition results of the main pollution factors of the rivers, this research selects COD$_{Cr}$, BOD$_5$, NH$_3$-N, TP, and COD$_{Mn}$, and analyzes the trend of water quality variation during each water period (high water period, level period, and dry period) from August 2014 to May 2017. According to the multi-year rainfall-runoff rule of the development zone, the general dry period refers to December, January, February, and March. The level period refers to April, May, and October and November, and the high-water period refers to June to September. According to the division of the above water periods, the trend of pollution degree of major pollution factors along the monitoring sections during the high-water period, level period, and dry period is analyzed. The concentration value of the pollution factors in each water period is taken as the average value of the monitoring values within the water period. The results of the analysis are shown in Figure 2. The abscissa indicates the water period and the ordinate indicates the concentration values of the COD$_{Cr}$, BOD$_5$, COD$_{Mn}$, NH$_3$-N, and TP.

From Figure 2, the water quality parameters show a different trend over time, and the same water quality parameter varies in different sections with great difference of variation trend. The water quality parameters of the S1 and S5 sections are relatively stable, and the water quality is relatively good. The overall water quality varies insignificantly with the water period, and the water quality of the remaining sections fluctuates significantly in different water periods. The overall water quality in the S2 section tends to get better, and COD$_{Cr}$, BOD$_5$, and COD$_{Mn}$ are relatively high in the dry season, while there is no obvious correlation between the nitrogen and phosphorus pollution and the change of the water period. In the S3 section, water quality deteriorates significantly in 2017, especially the two water quality indexes of ammonia-nitrogen and TP. From the water periods, the pollution during April to May of each year is relatively serious; the water quality at the S4 section shows a deteriorating trend as a whole, and the water quality gets worse in 2017, the water quality in the high-water period is good, and the water quality during the dry season and the level period between April and May is worst; the overall water quality of section S6 tends to get better, and the pollution during the normal period and high-water period from April to May each year is relatively serious. In 2016, the water quality of section S7 gets better compared to that of 2015 and 2014, but the water quality in 2017 deteriorates again. The overall trend of water quality in section S8 is not obvious. Water quality in the wet seasons

multiples of 7.2. Ammonia-nitrogen of 78.2% samples exceeds that specified in the category IV standard for surface water (1.5 mg/L), with the maximum over-standard multiples of 18.9. TP of 91.9% samples exceeds that specified in the category IV standard for surface water (0.3 mg/L), with the maximum over-standard multiples of 31.7. Among other pollutants, the over-standard rate of volatile phenol and petroleum is extremely low, only individual samples exceed the standard, which may be affected by the coincidental uncertainty factors; the over-standard rate of fluoride is 9.8%, indicating that about 40 samples exceed the standard among 408 samples, and are mainly concentrated in three sampling sections, S8, S9, and S10. There may be man-made pollution sources in the zone. The results show that the water quality of the inland river system in the zone suffers from serious organic pollution, leading to very poor water quality.

The coefficient of variation can reflect the degree of variation of each water quality index over the entire monitoring period (Du 2015). From the overall degree of variation of each indicator, which is shown in Table 3, the CV value indicates range from 6.6% to 97%, respectively, indicating that the two water quality parameters, ammonia-nitrogen and TP, fluctuate more strongly during the monitoring period, and are not evenly distributed in each section of the river system in the development zone, with great variation the degree to which they are affected by external sources of pollution.

According to the above statistical analysis results, the major pollutants of the river system in the development zone are ammonia-nitrogen, TP, COD$_{Cr}$, COD$_{Mn}$, and BOD$_5$. Among them, NH$_3$-N and TP are the main pollutants of the river system in the development zone.

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Temporal distribution characteristics

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Figure 2 | The temporal trend of the dominant contaminant concentrations in the inland water system (S1–S12). (Continued.)
Figure 2 | Continued.
of 2014 and 2015 is relatively heavy. Water quality in the dry periods of 2016 and 2017 is heavily polluted, which is mainly due to the development of the area and the source of pollution from agriculture. The pollution source shifts mainly from the orientation of agricultural surface source to point source pollution. From 2015 to 2016, the water quality at S9 section tends to get better, but the water quality in 2017 tends to deteriorate compared with the same period in 2015 and 2016, and the nitrogen and phosphorus pollution in the dry period in 2015 is more serious. The most serious water quality occurs in the high-water period; the water quality at S10 section is poor as a whole, the relative pollution in the high-water period is serious, and the water quality at S11 section is not obvious. The pollution in the level period between April and May is relatively serious.

Since the monitoring value of water quality is affected by many factors and shows great volatility, in order to accurately determine the trend of the water quality over time, this research uses SPSS 22.0 software to analyze the five major pollutions of 12 regular monitoring sections of rivers in the development zone, and Spearman correlation coefficient between the two series of material factors and 12 consecutive periods (see Table 4, $W_{p,0.05} = 0.506$).

As can be seen from Table 4, between August 2014 and May 2017, there are no significant changes in the trend of the five major pollutant indexes on the S1 section, indicating that the water quality was stable during the evaluation period. There is a significant decrease in COD$_{Cr}$ and TP at the S2 section ($p < 0.01$). The permanganate index, NH$_3$-N and BOD$_5$ fail to reach significant levels, and the variation trend is not obvious. NH$_3$-N and BOD$_5$ at the S3 section show a significant increase ($p < 0.05$), and the other three indexes show no significant variation. The trend of NH$_3$-N removal at the S4 section is not obvious, but the other four indexes show a significant increasing trend ($p < 0.05$). There was a significant increase in BOD$_5$ on the S5 section ($p < 0.05$). The trend of the other four indexes is not significant. The reduction trend of NH$_3$-N, BOD$_5$, and TP in the S7 section is extremely significant ($p < 0.01$), the trend of COD$_{Cr}$ reduction is significant ($p < 0.05$), and the variation trend of the permanganate index is not obvious. At the S8 section, NH$_3$-N is significantly reduced ($p < 0.01$), and the trend of the other four indexes is not significant. The indexes of the S9 section fail to reach significant levels and the water quality is stable. There is a significant increase in BOD$_5$ at the S10 section ($p < 0.05$). The trend

<table>
<thead>
<tr>
<th>Monitoring section</th>
<th>COD$_{Cr}$</th>
<th>BOD$_5$</th>
<th>NH$_3$-N</th>
<th>TP</th>
<th>COD$_{Mn}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.046</td>
<td>0.070</td>
<td>−0.346</td>
<td>0.185</td>
<td>0.057</td>
</tr>
<tr>
<td>S2</td>
<td>−0.685**</td>
<td>0.056</td>
<td>0.077</td>
<td>−0.643**</td>
<td>−0.305</td>
</tr>
<tr>
<td>S3</td>
<td>−0.207</td>
<td>0.573*</td>
<td>0.634*</td>
<td>−0.266</td>
<td>−0.301</td>
</tr>
<tr>
<td>S4</td>
<td>0.589*</td>
<td>0.575*</td>
<td>0.449</td>
<td>0.519*</td>
<td>0.619*</td>
</tr>
<tr>
<td>S5</td>
<td>−0.305</td>
<td>0.552*</td>
<td>0.382</td>
<td>−0.070</td>
<td>0.112</td>
</tr>
<tr>
<td>S6</td>
<td>−0.455</td>
<td>0.308</td>
<td>−0.329</td>
<td>−0.573*</td>
<td>−0.315</td>
</tr>
<tr>
<td>S7</td>
<td>−0.573*</td>
<td>−0.867**</td>
<td>−0.888**</td>
<td>−0.713**</td>
<td>−0.189</td>
</tr>
<tr>
<td>S8</td>
<td>−0.070</td>
<td>−0.434</td>
<td>−0.692**</td>
<td>−0.280</td>
<td>0.315</td>
</tr>
<tr>
<td>S9</td>
<td>−0.028</td>
<td>0.280</td>
<td>−0.497</td>
<td>−0.014</td>
<td>0.490</td>
</tr>
<tr>
<td>S10</td>
<td>−0.084</td>
<td>0.559*</td>
<td>−0.189</td>
<td>−0.217</td>
<td>0.224</td>
</tr>
<tr>
<td>S11</td>
<td>0.291</td>
<td>0.105</td>
<td>0.046</td>
<td>0.140</td>
<td>0.126</td>
</tr>
<tr>
<td>S12</td>
<td>0.204</td>
<td>−0.585*</td>
<td>0.042</td>
<td>0.211</td>
<td>0.373</td>
</tr>
</tbody>
</table>

*Relevant coefficients are significantly relevant at the level of 0.01 (one-side) ($p < 0.01$).

**Relevant coefficients are significantly relevant at the level of 0.05 (one-side) ($p < 0.05$).
of the other four indexes is not significant. The indexes of the S11 section fail to reach significant levels, and the trend of change is not obvious. BOD₅ at the S12 section shows a significant decrease \((p < 0.05)\). The trend of the other four indexes is not significant.

In summary, between August 2014 and May 2017, the water quality of the S7 section in the upstream of the Jiebai River is significantly improved. The water quality of the S4 section in the Xiao budong River deteriorates significantly, and individual indicators have increased or decreased in the remaining sections. However, the overall trend of variation is not obvious.

### Analysis of the variation trend of water quality categories

In order to further determine the trend of water quality variation over time, the number of IV, V, and inferior V categories of water quality sections in the monthly samples between August 2014 and May 2017 is used for statistics, analyzing the river water quality categories in the zone over time. The relevant results are shown in Figure 3.

The water quality category trend is tested by the Spearman rank relational coefficient method, and the variation trend of water quality during the monitoring period is significant. The test results are shown in Table 5 \((W_{p;0.05} = 0.306)\).

As demonstrated by Table 5, between August 2014 and May 2017, the proportion of category IV sections failed to reach a significant level and remained stable. The proportion of category V sections shows a significant upward trend, and the proportion of inferior category V sections shows a significant downward trend. The results show that the river water environment control measures in the development zone have made some achievements, and the treated parts of the inferior category V section have achieved category V water quality, but there is still a definite gap from the requirements for achieving category IV water quality.

### Spatial distribution characteristics

By analyzing the spatial distribution characteristics of the five major pollution factors CODCr, BOD₅, NH₃-N, TP, and CODMn of 12 regular monitoring sections of the river system in the development zone, the pollution of each section can be better reflected. Statistically, the over-standard rate and the average over-standard multiples of the month-to-month value of each section and each pollution factor...
between August 2014 and May 2017 are measured, and the results are shown in Figure 4.

From Figure 4, during the monitoring period, COD$_{Cr}$ of all 12 sections exceeds the standard, among which the over-standard ratios of sections S1–S5 and S12 are lower than 50%, and the average over-standard multiples of S1, S3, and S5 are negative, indicating that the mean concentration of COD$_{Cr}$ at three sections fails to exceed the
standard, and the average over-standard multiples of S2, S4, and S12 are lower, being 0.06, 0.11, and 0.12, respectively; the \( \text{COD}_{\text{Cr}} \) exceeded the standard rate and averaged over-standard multiple of the S6–S11 sections were high, and the \( \text{COD}_{\text{Cr}} \) pollution was relatively serious. \( \text{NH}_3\text{-N} \) and TP are the two most serious pollutants in the river system in the development zone. Except for the S2 section, \( \text{NH}_3\text{-N} \) exceeding the standard exceeds 50%, of which, S1, S4, and S9 exceed the standard rate of 100%. The average exceeding multiples for each section are above zero, the average over-standard multiple of the S4 section is 5.00 times. The over-standard rate of TP in each section was more than 80%, and the average over-standard multiple of each section was also greater than zero. The average over-standard multiple of the S7 section was 6.29 times. Permanganate index did not exceed the standard in the S1 section, the remaining standards exceeded the rate of 8.8% to 73.5%, S1–S5 cross-section average of the multiples was less than zero, S6–S12 cross-section average of the multiples was between 0.04 and 0.47, and S10 section over-standard multiples were maximum. The over-standard rate of \( \text{BOD}_5 \) at the 12 sections is between 29.4% and 82.4%. The average over-standard multiples of the S1 and S5 sections are negative, and the over-standard multiples of the remaining sections are between 0.26 and 0.85. The S7 and S10 sections have the maximum over-standard multiples.

Generally speaking, according to the analysis of the over-standard ratio and the mean over-standard multiple of each section, the S6 to S11 sections have serious pollution, and are mainly distributed in the downstream of Jiebai River, Pengbai River, Xiaodungou River, Huangbai River, and Yubai River. In addition, the ammonia-nitrogen pollution of the S4 section in Xiaobudong River is very serious.

**Figure 4** | Continued.
CONCLUSIONS

The statistical analysis results of water quality parameters show that the main pollutants of the river system in the development zone are NH3-N, TP, CODCr, CODMn, and BOD5. Among them, NH3-N and TP are the most serious pollutants, and are the most important pollutants in the river system of the development zone. Nitrogen and phosphorus mainly come from industrial wastewater discharged from chemical plants along inland rivers, urban domestic sewage, and agricultural non-point source pollution inputs.

The spatial-temporal characteristic analysis results of the main pollutants show that at a time scale, the water quality parameters vary over time with great fluctuation, and without obvious changes; at the spatial scale, the S6 to S11 sections have serious pollution and are mainly distributed in the downstream of Jiebai River, Pengbai River, Xiaodungou River, Huangbai River, and Yubai River. In addition, the ammonia-nitrogen pollution of the S4 section in Xioabudong River is very serious.

The Spearman rank relational coefficient analysis results show that between August 2014 and May 2017, the water quality of the S7 section tends to get better, and the water quality of the S4 section tends to get worse, and the overall variation trend of the remaining sections is not obvious. The variation trend of the portion of category IV sections fails to reach the significant level, and remains stable. The portion of category V sections tends to an upward trend. The portion of the inferior category V sections tends to a downward trend.

In general, during the period from August 2014 to May 2017, the water quality of the rivers was relatively stable in the development zone. Nitrogen and phosphorus are the key to water environment management in rivers in the development zone, and are caused by non-point source pollution.

REFERENCES


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