Characteristics and Changing Trend of Water Pollution in North Plain of Shang Yu

Lixin Wang\textsuperscript{1a}, Wanying Guo\textsuperscript{2,3b*}, Ziming Wang\textsuperscript{3c}, Pengcheng Yao\textsuperscript{3d}, Guojian Hu\textsuperscript{3e} and Aiju You\textsuperscript{3f}

\textsuperscript{1} Shaoxing Shangyu District Environmental Monitoring Station, Shangyu 312300, China
\textsuperscript{2} College of Hydrology and Water Resources, Hohai University, Nanjing 210098, China
\textsuperscript{3} Zhejiang Institute of Hydraulics & Estuary(Zhejiang Surveying Institute of Estuary and Coast), Hangzhou 310020, China.

\textbf{Abstract.} The plain river network area is strongly influenced by human activities, with flat terrain, weak hydrodynamics and poor water quality. Previous studies have mostly focused on water quality categories, lacking an overall study of the pollution characteristics of water bodies and their changing trends. In order to comprehensively grasp the water pollution situation of the river network in the northern Yu Plain, this study scientifically analysed the water quality characteristics of the river network in the northern Yu Plain and its correlation with rainfall through regression analysis and MK mutation test based on the long series of water quality and rainfall data of the Dongjin River and Unity River in the northern Yu Plain from 2017-2021. The results show that the correlation between water quality and rainfall in the river network of the northern Yu Plain is not significant, reflecting that the pollution in the watershed is still controlled by point sources, but there is a trend for the Unity River to change to non-point source control; the COD\textsubscript{mn}, NH\textsubscript{3}-N and TP of the Dongjin River and Unity River all show a high positive correlation, and the correlation of the Dongjin River is higher than that of the Unity River; the MK mutation test shows that there is no significant mutation point in the Dongjin River in the last five years, and the Unity River has no significant mutation point in the last five years. The MK mutation test shows that there is no significant mutation point in Dongjin River in the past 5 years, and there is a sudden change in water quality in Unity River from 2017 to 2018, and the water quality indexes show a decreasing trend in general, but remain stable in recent years. The study aims to academically reveal the dominant factors, pollutant characteristics and water quality trends of pollutants in rivers in the northern Yu Plain, and to propose scientific references for the pollution prevention and control of other plain river networks.

\section{Introduction}

In China's plain river network, the deterioration of urban water quality is a significant issue for the water environment and water security. The rapid urbanization of today has made it so that the decline in urban water quality is not only a significant barrier to China's economic development, but also directly impacts urban ecological security and is linked to the health issues of the local populace\cite{1}. One of the most active regions of economic development in China is the river network in the middle and lower reaches of the Yangtze River plain. Several urban river networks have substantially degraded biological conditions and water quality. There is a high concentration of nitrogen and phosphate fertilizers as well as organic contaminants that consume oxygen. Urban development must now prioritize resolving the pollution of urban waterways and restoring their ecology\cite{2}.

Rainfall-induced urban surface runoff is typically ranked as the second biggest cause of water environment contamination in cities. The principal contaminants in rainfall runoff, including phosphorus, nitrogen, and other nutrients, are dumped into bodies of surface water, affecting the environmental quality of the water. Many scholars believe that there is a significant correlation between rainfall and non-point source pollution production, including exponential function\cite{3}, power function\cite{4}, logarithmic function\cite{5} and quadratic function\cite{6}. For example, in the Xinfenghe River Basin, the concentrations of COD, ammonia nitrogen and TP in the exit section of the basin show a decreasing trend year by year, and the concentrations of COD, ammonia nitrogen and TP are higher in moderate rain and heavy rain, but lower in rainstorm and extremely heavy rain\cite{7}. The content of nutrient elements in river channels is significantly affected by rainfall and runoff\cite{8}. Since the research on the performance evaluation of urban runoff non-point source pollution control projects started late in our country, the implementation efficiency evaluation of urban runoff non-point source pollution control projects was lacking\cite{9}, further research was needed on whether non-point source pollution was the leading factor of urban water pollution.

\textsuperscript{1}2297264064@qq.com,\textsuperscript{2,3b}guo_wanying@qq.com,\textsuperscript{3}wangziming1301@126.com,\textsuperscript{4}yaopc7283@163.com,\textsuperscript{5}hugj@zjwater.gov.cn,\textsuperscript{6}youajijzjwater.gov.cn

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River water pollution can be divided into two kinds according to different pollution sources. One is point source pollution, which refers to the pollution from a single pollution point, such as chemical plant wastewater discharge outlet, chimney exhaust outlet, etc. The first is non-point source pollution, which refers to pollutants from a wide area, such as rainfall, urban roads, agricultural fertilizers, forest logging, etc. Non-point source pollution also known as non-point source pollution, is mainly composed of nutrients such as nitrogen and phosphorus, pesticides, and various atmospheric particles, which enter the water, soil or atmospheric environment through surface runoff, soil erosion, farmland drainage and other ways. Because of its more extensive and random sources, it is also known as non-point source pollution. Compared with point source pollution, the sources of non-point source pollution are scattered and diverse, the pollution boundary and location are difficult to judge and identify, the pollution sources are random, the causes are complex, and the incubation period is long, so the prevention and control is very difficult \[10\]. According to the statistics of relevant ministries and commissions, the sewage treatment rate of Chinese cities is as high as 90%, and there are three kinds of urban rivers with black odor. First, the rivers in cities with high pipe network coverage rate are black odor; second, the rivers in cities with high sewage interception rate are black odor; third, the rivers are not black odor in sunny days but black odor in rainy days. Black and smelly water reduces residents’ perception, experience and quality of life, and restricts local ecological and economic development to a certain extent. Many developing countries similar to China are faced with such problems. As there is no precedent for technical solutions, it is urgent to explore and solve the urgent problems \[11\].

Yubei Plain is one of the important agricultural production bases and an important agricultural irrigation area. The water body in the river network is the important water source of Shaoxing City. The pollution degree of the water body in the river network is directly related to the local crop production and the living quality of the residents. However, with the rapid development of economy and the increase of population, the problem of water pollution in the river network of Yubei Plain is becoming more and more serious. Therefore, it is of great significance to make effective pollution control measures and protect the local environment to study the characteristics and changing trend of water pollution in the river network of Yubei Plain. Based on the water quality monitoring data of the river network of the northern Plain in recent years, this paper intends to discuss the water pollution characteristics and its changing trend, so as to provide a scientific analysis for the prevention and control of local water environmental pollution.

2 Materials and Methods

2.1 Regional Overview

Shang Yu District topography south high north low, south low hills and north water network plain area mixed, south low hills are divided into two branches, southeast of Siming mountain after pulse, relatively high, covering Shang Yu annual average temperature 16.4℃, frost-free period about 251 days, the general annual rainfall 1400 mm. The study area of this paper is the northern river network area of Shang Yu, located on the right bank of the Cao Crescent River, extending to the junction of Yuyao in the east, Yucheng district in the west, East Zhejiang diversion project in the south, and Hangzhou Bay in the north, with a drainage area of about 326km². The average width of Tuanjie River and Dongjin River is 40m ~ 60m, both of which run north-south and drain into Qiantang River in the north. Under the influence of sluice control, Tuanjie River and Dongjin River basically form two relatively independent water systems in the north of East Zhejiang Water diversion project, namely the west line and the east line. The main land use types in the west line from south to north are urban area and aquaculture area, while the main land use types in the east line from south to north are urban area, agricultural area and industrial area. To comprehensively understand the water quality of the northern plain of Shang Yu, clarify the main problems affecting the water quality of the network and their causes. It is very important for guiding the improvement of the overall water environment quality and the protection and restoration of regional ecological environment in the northern Plain of Shang Yu.

2.2 Data Description

This study is based on water quality and rainfall data, including daily scale pollutant data and daily scale rainfall data from 2017 to 2021 and daily scale pollutant and rainfall data from June 2022. The first bridge is situated in the middle reaches of the Dongjin Drainage River, and the second gate of the water quality monitoring station is situated at the part of the Tuanjie River on the west line. The detection technique adheres to unified national criteria. The rainfall data during this period came from Xiaoyue Station, the nearest rain measuring station near the study area. According to the water quality assessment requirements of the north Plain of Shang Yu, COD, NH-N and TP were selected as representative water quality parameters to analyze the characteristics of pollution change and its response to rainfall in the north plain of Shang Yu.

2.3 Analysis Method

Data were analyzed and mapped by Arcgis, Excel, R language, Matlab and other software.
(1) Regression analysis. The COD\(_{\text{mn}}\), NH\(_3\)-N, TP concentration and rainfall data of Bridge No.1 and Gate No.2 were selected, and the regression calculation of rainfall and water quality indexes was carried out by using R language and the correlation was analyzed. As the existence value of rainfall data is 0, it is the revised data. A certain value Re (Re > 0) is added on the basis of the original rainfall, and logarithmic transformation is carried out on the revised rainfall data Rx. The regression analysis of COD\(_{\text{mn}}\), NH\(_3\)-N, TP concentration and rainfall was carried out by using R language software.

\[
R_{ix} = R_{ij} + R_{e} \quad (1)
\]

\[
C_i = \ln(R_{ix}) \quad (2)
\]

\[
\beta = \frac{\sum (C_i - \bar{C})(R_{ix} - \bar{R}_e)}{\sqrt{\sum (C_i - \bar{C})^2 \sum (R_{ix} - \bar{R}_e)^2}} \quad (3)
\]

(2) MK (Mann-Kendall) mutation test. MK mutation analysis can be used to analyze the mutation process of water quality index, the trend of pollution characteristics and the causes.

\[
S_K = \sum_{i=1}^{k} \sum_{l=i}^{n-1} a_{ij} (k = 2, 3, 4, \ldots, n) \quad (4)
\]

\[
a_{ij} = \left\{ \begin{array}{ll}
1 & X_i > X_j \quad 1 \leq j \leq l \\
0 & X_i \leq X_j 
\end{array} \right. \quad (5)
\]

\[
UF_k = \left[ \frac{\sum_{i=1}^{k} (S_K)}{\sqrt{\text{var}(S_K)}} \right] (k = 1, 2, 3, \ldots, n) \quad (6)
\]

In the formula, UF\(_k\) is a statistical series calculated based on the standard normal distribution and X time series, with significance level \(\alpha\); When the condition for \(UF_k > U_{\alpha/2}\), significant trend change. Generally, the positive and negative values of UF\(_k\) represent the rise or fall of the trend, and the nodes of the time series corresponding to the intersection of the UB\(_k\) curve are the abrupt periods.

3 Results and analysis

3.1 Changes in river network pollutants

The North Plain of Shang Yu’s river network’s water quality progressively improved between 2017 and 2021. The concentration of NH\(_3\)-N and TP dramatically dropped, and the total water quality gradually improved from badly polluted poor Class V water to Class V water. Table 1 shows that the annual mean of COD\(_{\text{mn}}\) concentration for Bridge No.1 is steady at 4.0–5.0, TP concentration is less than 0.3, and NH\(_3\)-N is the main pollutant. In January 2017, the NH\(_3\)-N value of Bridge No.1 rose to a maximum of 7.90. After that, there was a clear downward tendency, with the annual average value typically falling between 0.5 and 1.0. In comparison to 2018, the yearly mean COD\(_{\text{mn}}\) concentration at Gate No.2 varied and fell by 16.8%, 20.6%, and 10.9%, respectively, from 2017 to 2021. The mean concentration of NH\(_3\)-N and TP in 2021 decreased by 46.5% and 38.0%, respectively, compared to that in 2017. NH\(_3\)-N and TP concentrations likewise progressively decreased. The main stations in the river network of the Yubei Plain’s main stations showed a downward trend in the water quality concentration index over the course of the monitoring period, and the control effect was notable.

<table>
<thead>
<tr>
<th>Year</th>
<th>COD(_{\text{mn}}) Bridge No.1 concentration (mg/L)</th>
<th>COD(_{\text{mn}}) Gate No.2 concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TP Bridge No.1</td>
<td>TP Gate No.2</td>
</tr>
<tr>
<td>2017</td>
<td>4.64</td>
<td>0.27</td>
</tr>
<tr>
<td>2018</td>
<td>4.10</td>
<td>0.17</td>
</tr>
<tr>
<td>2019</td>
<td>4.51</td>
<td>0.19</td>
</tr>
<tr>
<td>2020</td>
<td>4.77</td>
<td>0.17</td>
</tr>
<tr>
<td>2021</td>
<td>4.59</td>
<td>0.18</td>
</tr>
</tbody>
</table>

3.2 Response of Pollutant Change to Rainfall

The linear regression approach was used in this paper to establish the association between rainfall and concentrations of COD\(_{\text{mn}}\), NH\(_3\)-N, and TP in order to explore the change characteristics and reasons of the link between precipitation in the basin and water quality indices in the exit section. Figure 1 displays the rainfall and response trend for Bridge No.1 and Gate No.2 from 2017 to 2021, respectively. According to the analysis of correlation coefficient, Bridge No.1’s COD\(_{\text{mn}}\), NH\(_3\)-N, TP concentration, and rainfall correlation coefficients for the years 2017 to 2021 are 0.070, -0.017, and 0.035, respectively, while Gate No.2’s corresponding correlation coefficients are -0.066, 0.025, and 0.121, showing that Gate No.2’s correlation coefficient is typically higher than Bridge No.1’s. For example, NH\(_3\)-N No.2 has a correlation coefficient between TP and rainfall that is 71.07% greater than Bridge No.1’s. The test number of each pollutant concentration at Bridge No.1 and Gate No.2 is considerably higher than 0.05, according to the test number with 95% confidence. The analysis’s findings make it clear that there is little correlation between changes in pollutant concentration and rainfall in the research basin. The index concentration has no appreciable dilution effect as the rainfall rises. As a result, there is no meaningful connection between the Yubei Plain’s river network pollution and the non-point source pollution of rainfall, and there is no meaningful link.
3.3 Analysis of Pollutant Characteristics

The correlation study charts for Bridge No.1 and Gate No.2 are shown in Figure 2. It has been discovered through study that there is a strong correlation between pollutants, particularly NH$_3$-N and TP, and indicators like PH, WT, DO, and turbidity. When PH is compared to different indicators, its correlation with DO is significantly higher than that of other indicators; for Bridge No.1, the correlation between PH and DO approaches 0.68 positive correlation, indicating a highly significant correlation. For Bridge No.1 and Gate No.2, WT and Cond displayed a significant negative correlation, with WT and Cond both exceeding -0.5.

Negative correlations are found between WT and DO, DO and turbidity, and WT and turbidity. While the correlation changes between river segments, it remains constant within a single river segment. For instance, in Bridge No.1 and Gate No.2, the correlation between the three categories is -0.25 to -0.5. There is a favorable association between TP, NH$_3$-N, and COD$_{Mn}$. Bridge No.1 has a correlation range of 0.25 to 0.75, with NH$_3$-N and TP having a particularly strong correlation of up to 0.69. In Gate No.2, the three variables' correlations range from 0 to 0.5, and NH$_3$-N continues to have the highest correlation with TP. As a result, there is a substantial correlation between COD$_{Mn}$, NH$_3$-N, and TP, with NH$_3$-N having the best correlation to TP.
3.4 Abrupt Change of Water Quality in the North Plain of Shang Yu

Using the MK test, the abrupt changes in COD$_{Mn}$, NH$_3$-N, and TP concentrations of Bridge No.1 and Gate No.2 from 2017 to 2021 were examined in order to identify the primary reasons of water quality changes in the North Plain of Shang Yu. The outcomes are displayed in Figure 3. As seen in the figure, not all concentration indicators experience abrupt points between 2017 and 2021, but the majority of concentration indicators exhibit a decent downward trend after doing so. No evident mutation site was found in Bridge No.1 during the research period within the 1% significance level. Only in 2018, NH$_3$-N concentration and TP concentration showed a substantial drop. COD$_{Mn}$ concentration only exhibited a significant decline in 2018. In May 2017, there was a dramatic change in the NH$_3$-N concentration in Gate No.2, and after that, the NH$_3$-N concentration significantly decreased. In May 2018, there was a clear mutation point in the TP concentration, and the TP value also immediately began to plummet.

![Fig.3. Test results of concentration MK of COD$_{Mn}$, NH$_3$-N and TP in Bridge No.1 and Gate No.2](image)

4 Conclusion

(1) In the north Plain of Shang Yu, there was no discernible relationship between river water pollution and rainfall. In the study basin, there is typically no link between changes in pollutant concentration and rainfall, and point sources continue to be the primary means of controlling pollution. Pollutant concentration changes are not significantly influenced by changes in rainfall in the basin, and the index concentration has no discernible dilution effect. Yet, Tuanjie River has a propensity to switch to non-point source control as seen by the significant correlation coefficient between TP concentration and rainfall in Tuanjie River.

(2) Dongjin River and Tuanjie River both displayed high positive correlations in COD$_{Mn}$, NH$_3$-N, and TP, with Dongjin River's correlation being larger than Tuanjie River's. In the correlation study, COD$_{Mn}$, NH$_3$-N, and TP exhibited a good association compared to the poor correlation between rainfall and COD$_{Mn}$, NH$_3$-N, and TP. A significantly larger positive association was found between COD$_{Mn}$ and NH$_3$, COD$_{Mn}$ and TP, and particularly between NH$_3$ and TP. In the Tuanjie River, there was also a strong positive link between COD$_{Mn}$ and NH$_3$, COD$_{Mn}$ and TP, and NH$_3$ and TP, however it was not as strong as it was in the Dongjin River.

(3) While Tuanjie River's water quality had a mutation in 2017–2018, Dongjin River's water quality had not clearly changed in the previous five years, according to the MK mutation test, preserving general stability. Throughout the study period, no evident mutation point was found in the Dongjin River, yet COD$_{Mn}$ concentration and NH$_3$-N concentration both drastically dropped between 2018 and 2021. The levels of NH$_3$-N and TP in the Tuanjie River clearly changed between 2017 and 2018, after which they clearly reduced while the water quality indices showed a good upward trend.

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References


