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Spatio-Temporal Simulation Analysis on Water Environment of Typical Eutrophic Tributaries of Three Gorges Reservoir Based on MIKE 21

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Abstract. In recent years, the eutrophication in the typical tributaries of the Three Gorges Reservoir has attracted widespread attention. In the present paper, three typical eutrophic tributaries in the Three Gorges Reservoir area, that is, Xiaojiang River (Pengxi River), Daning River and Xiangxi River, were selected for research, and a two-dimensional hydrodynamic and water quality coupling model that is for the area from Zhutuo to dam site was constructed by using MIKE 21 software. On this basis, the temporal and spatial distribution of pollutants in three tributaries in 2021 was further simulated and analyzed. The results showed that: (1) The coupling model after calibration and validation had good simulation accuracy for hydrodynamic and water quality indexes in the reservoir area, and the simulation effect was in good agreement with the measured results; (2) The concentration of each pollutant was closely related to the change of water level and water quantity. From the highstand period to the pre-discharge stage (January-June), the concentrations of total nitrogen and total phosphorus increased, which were very high from the post-discharge period to the lowstand period (July-September); (3) The concentration of pollutants in the confluence of the main stream and tributaries was high due to the backward flow of the main stream. To sum up, the higher concentration of pollutants and the higher water temperature in spring and summer were conducive to the rapid reproduction of algae and other plankton, resulting in eutrophication, and the algal bloom was easy to break out in the reservoir area. During the water storage period and highstand period (October-December), the concentrations of total nitrogen and total phosphorus showed a downward trend, mainly due to the self-purification of water and the degradation of pollutants. The research conclusion can provide a reference for water quality evaluation, water supply safety and pollutant treatment in the Three Gorges Reservoir area.

Keywords. Three Gorges Reservoir, MIKE 21 model, hydrodynamic and water quality coupling, eutrophication

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1. Introduction

Since the impoundment of the Three Gorges Reservoir, the eutrophication and algal bloom in the backwater areas of its tributaries have become one of the most concerning ecological and environmental problems in this area. For this reason, scholars have carried out a great deal of research. However, there are inevitably some limitations in the traditional research methods have certain limitations because the reservoir area is so large that it is difficult to collect data, and the continuity of data in time and space is hard to be ensured. Therefore, the simulation of the water environment and ecology model based on hydrodynamic conditions in the reservoir area has gradually become a research hotspot. The overseas research on water environment and water ecological models started in the 1960s to the 1980s. The related models are constantly improved, and the most representative one is the two-way coupled water quality model [1]. After the 1980s, the two-dimensional water quality model was developed and matured, and the solution technology of a multi-dimensional numerical model was also produced in this period. At home, the research on the water quality model started late. In the 1990s, the water quality model was gradually applied to the design of a water quality optimization scheme. After the 21st century, it has gradually developed in a multi-dimensional and multi-level direction [2]. Among them, MIKE 21 hydrodynamic-water quality coupling model is a comprehensive, deterministic and completely distributed hydrological model. Besides, as an important part of MIKE series software, it can be used to simulate the flow of rivers, lakes, reservoir areas and oceans, so it has been widely used and achieved good research results. In the study of Li et al. [3], a two-dimensional model based on MIKE 21 was built in Datong Lake under different connectivity dispatching schemes. Yang et al. [4] used MIKE 21 to simulate the diffusion and migration of pollutants in the sewage outlet along the Yangtze River in the Huangshi section under normal and abnormal sewage discharge conditions, and predicted the spatial and temporal variation of pollutants under different sewage discharge conditions. According to Xu et al. [5], the Yangwei District of Shenzhuang, Nanxun, Huzhou City, Zhejiang Province was studied, and a water quality and hydrodynamic coupling model was established with MIKE software to improve the hydrodynamic conditions of the river. After studying the several years of the water quality data of the Hanjiang River for many years, Zhao et al. [6] established the MIKE 21 model to simulate the dynamic change process of water quality in the Hanjiang River, and studied and analyzed the dynamic diffusion process of pollutants. With MIKE 21 model, Yang et al. [7] simulated the hydrodynamic-water quality coupling of Tangxun Lake. On this basis, the improvement of hydrodynamic force in the scheme of connecting internal water systems and the influence of water diversion from Dongba River and non-water diversion on the water quality of Tangxun Lake after implementing the pollution reduction scheme were demonstrated. Liu et al. [8], with MIKE 21 model, established a model of the Yangtze River where the sewage outlet of Jingzhou Zhonghuan Sewage Treatment Plant is located, simulated the migration and diffusion of major pollutants such as COD, BOD_5 and ammonia nitrogen in the Yangtze River, and analyzed the influence scope and degree of sewage discharge on the water quality of the Yangtze River. Taking the newly-built ecological artificial lake in the key area of Zhangyan Town, Jinshan District, Shanghai as an example, the flow field of the lake and its surrounding river network was numerically simulated by using the MIKE 21 model in the study of Sun et al. [9]. Besides, Gong et al. [10] used MIKE 21 model to simulate and analyze the water quality of Nansi Lake under multiple scenarios.

In order to explore the water environment problems in the typical eutrophic tributaries of the Three Gorges Reservoir, the water quality model is necessary, for it is a mathematical description of the variation law of pollutants in the water environment, can simulate the variation law of internal factors in the water body, make qualitative and quantitative analysis of pollutants, and provide simulation results from multiple time and space angles, which can effectively make up for the deficiency of prototype observation. Therefore, in the present study, a hydrodynamic-water quality-water ecological coupling model of the Three Gorges Reservoir area based on MIKE 21 was built based on the measured data, and the temporal and spatial distribution of three main pollutant indexes, namely total nitrogen (TN), total phosphorus (TP) and dissolved oxygen (DO), in Xiaojiang River (Pengxi River), Daning River and Xiangxi River was further simulated and analyzed. The research results have important reference value for local water resources management and protection.

2. Materials and Methods

2.1. Study Area

As shown in Figure 1, the Three Gorges Reservoir is located between 105°44’-111°39’ east longitude and 28°32’-31°44’ north latitude. Starting from Yiling District, Yichang City, Hubei Province in the east and reaching Jiangjin District, Chongqing City in the west, it is distributed along the Yangtze River, involving 25 counties and districts [11].

The reservoir area has developed water systems, among which the main stream of the Yangtze River is about 600 kilometers long, and the large tributaries are the Jialing River and the Wujiang River. In addition, the spatial and temporal distribution of precipitation in this region is uneven, with the average annual rainfall between 1200 mm and 1400 mm.

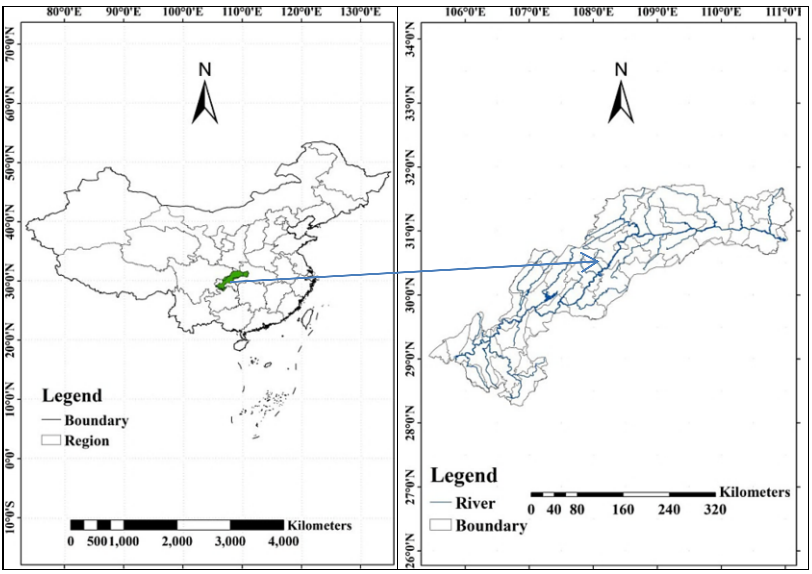


Figure 1. Study area.

2.2. Data Materials

In the present study, the hydrodynamic data used mainly include the daily measured flow data of main stream Zhutuo section in 2021 and 14 tributaries, such as Wujiang, Yandu, Daning, Jialing, Qijiang, Longxi, Mudong, Dahong, Quxi, Longhe, Xiaojiang, Meixi, Liangdou and Xiangxi River, and the daily measured water level data of dam site in 2021.

The water quality data used in the study are mainly the daily measured concentration data of TN, TP and DO in 2021 in the Zhutuo section, 14 tributaries, dam sites, as well as Sujia section, Peishi section, Jiangjin Bridge section, Baidicheng section, Heshangshan section and Shaiwangba section etc.

2.3. Method

In this study, a hydrodynamic-water quality-water ecological coupling model based on MIKE 21 was constructed, which mainly consists of hydrodynamic (HD), advection-diffusion (AD) and ECO-Lab modules. In the present study, the measured flow data of the Zhutuo section and 14 tributaries were used as the input data of the upper boundary (entrance) of the model, and the measured water level data of the dam site as the input data of the lower boundary (exit). Besides, the boundary of the reservoir was converted into WGS_1984_UTM_48N projection coordinates according to the latitude and longitude. According to the projection coordinates, the simulated boundary of the Three Gorges Reservoir was obtained in MIKE software, which was designed as calculation areas for triangular grid division, with the minimum angle of the grid of 30°, as shown in Figure 2. The model parameter calibration and verification period is 2021, and the simulation period is 2021. In view of the requirements for model stability and computational efficiency, the time step was set as 600 s.

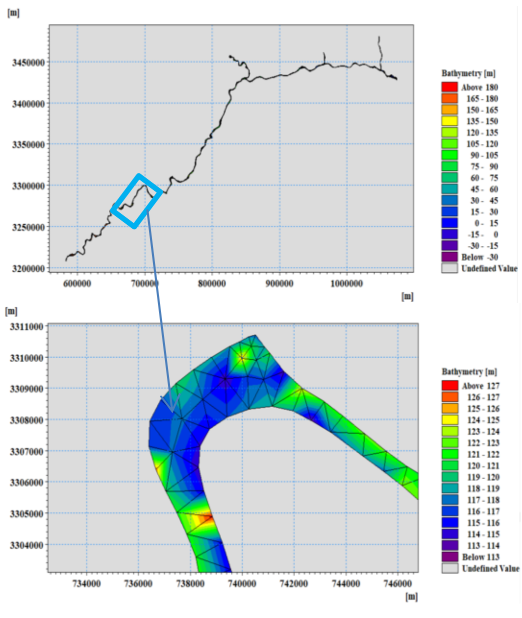


Figure 2. Gridding and terrain schematic diagram.

2.3.1. HD Module

The upstream inflow boundary of the Yangtze River main stream, the inflow boundary of 14 branches and the outflow boundary of the dam site were determined according to the land-water boundary conditions of the river channel and the incoming river. Besides, the daily measured data in 2021 were adopted.

The data input is shown in Figures 3 and 4.

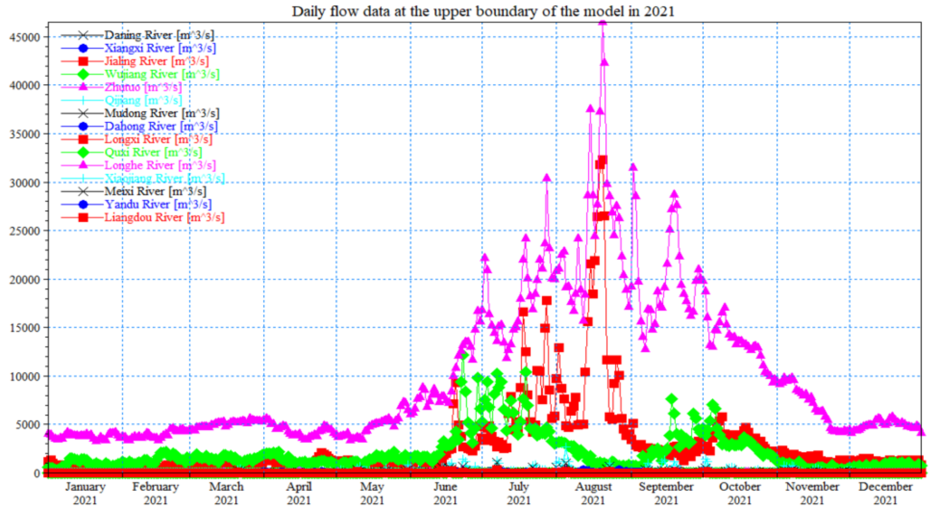


Figure 3. Daily flow data at the upper boundary of the model in 2021.

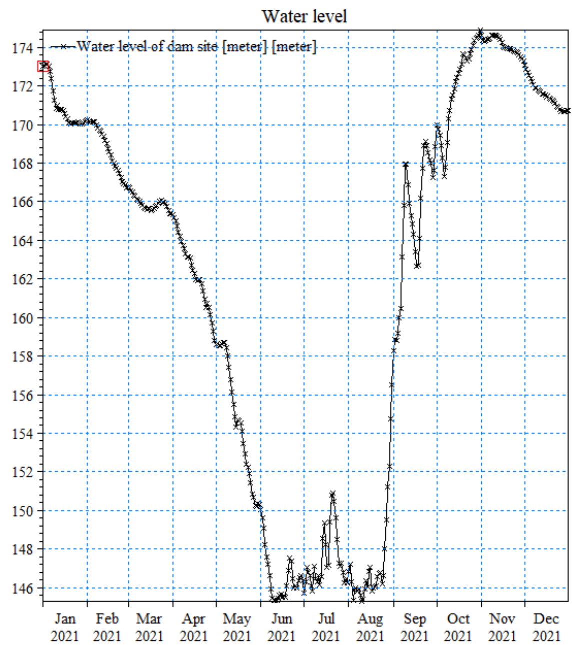
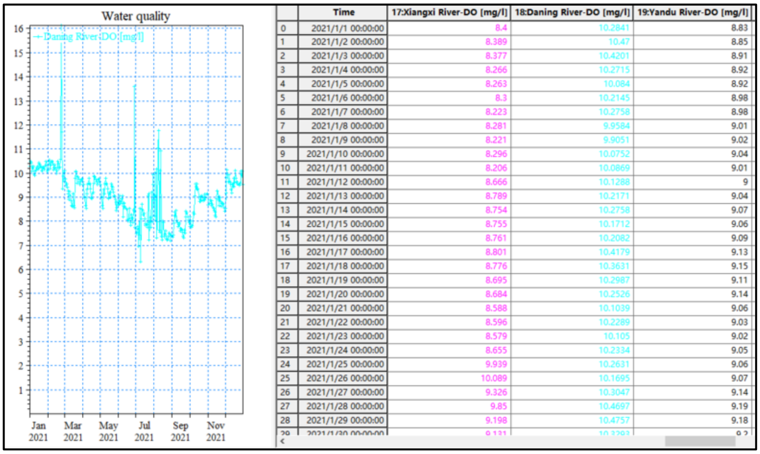


Figure 4. Daily water level data at the lower boundary (dam site) of the model in 2021.

2.3.2. AD and ECO-Lab Module

In the present study, the daily concentration of ammonia nitrogen, permanganate, TN, TP and DO at Zhutuo Section, 14 tributaries and the dam site in 2021 were used as the water quality boundary of the AD module and ECO Lab module, in which the daily measured concentration of DO at the inlet of Jialing River is shown in Figure 5.



	Time	17:Xiangxi River-DO [mg/l]	18:Daning River-DO [mg/l]	19:Yandu River-DO [mg/l]
0	2021/1/1 00:00:00	8.4	10.2841	8.83
1	2021/1/2 00:00:00	8.389	10.47	8.85
2	2021/1/3 00:00:00	8.377	10.4201	8.91
3	2021/1/4 00:00:00	8.266	10.2715	8.92
4	2021/1/5 00:00:00	8.263	10.084	8.92
5	2021/1/6 00:00:00	8.3	10.2145	8.98
6	2021/1/7 00:00:00	8.223	10.2758	8.98
7	2021/1/8 00:00:00	8.281	9.9584	9.01
8	2021/1/9 00:00:00	8.221	9.9051	9.02
9	2021/1/10 00:00:00	8.296	10.0752	9.04
10	2021/1/11 00:00:00	8.206	10.0869	9.01
11	2021/1/12 00:00:00	8.666	10.1288	9
12	2021/1/13 00:00:00	8.789	10.2171	9.04
13	2021/1/14 00:00:00	8.754	10.2758	9.07
14	2021/1/15 00:00:00	8.755	10.1712	9.06
15	2021/1/16 00:00:00	8.761	10.2082	9.09
16	2021/1/17 00:00:00	8.801	10.4179	9.13
17	2021/1/18 00:00:00	8.776	10.3631	9.15
18	2021/1/19 00:00:00	8.695	10.2987	9.11
19	2021/1/20 00:00:00	8.684	10.2526	9.14
20	2021/1/21 00:00:00	8.588	10.1039	9.06
21	2021/1/22 00:00:00	8.596	10.2289	9.03
22	2021/1/23 00:00:00	8.579	10.105	9.02
23	2021/1/24 00:00:00	8.655	10.2334	9.05
24	2021/1/25 00:00:00	9.939	10.2631	9.06
25	2021/1/26 00:00:00	10.089	10.1695	9.07
26	2021/1/27 00:00:00	9.326	10.3047	9.14
27	2021/1/28 00:00:00	9.85	10.4697	9.19
28	2021/1/29 00:00:00	9.198	10.4757	9.18
29	2021/1/30 00:00:00	9.131	[illegible]	9.2

Figure 5. Data input of water quality boundary concentration in 2021.

In addition, the daily average concentration data of pollutants in the Cuntan section, Qingxichang section, Jiangjin Baisha section, Jiangjin Qingcaobei section, Fengshouba section, Lidu section, Zhongxian Sujia Waterworks, Zhiping Street, Qijiang Jiangjin Estuary, Changsha Dam Reservoir and Baima Town were interpolated as the initial concentration input of the water quality module. This paper takes the interpolation result of the initial concentration of ammonia nitrogen as an example, as shown in Figure 6.

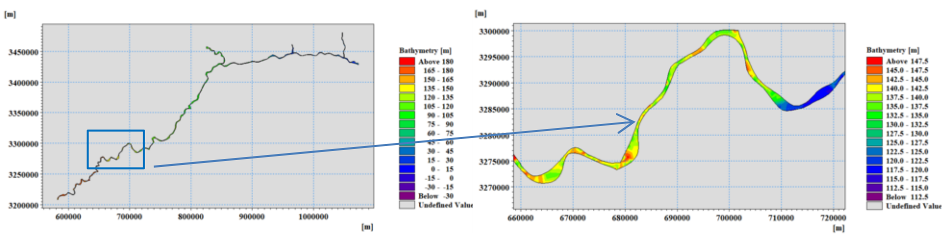


Figure 6. Spatial interpolation results of initial concentration of ammonia nitrogen.

3. Results

3.1. Model Calibration and Verification

3.1.1. Calibration Results

In this study, parameters contained in the HD module, AD module and Eco Lab module were calibrated respectively, and the results are shown in Table 1.

Table 1. Parameter calibration results.

Modules	Parameter	Calibration results	Unit
HD module	Dry depth	0.005	m
	Wet depth	0.1	m
	flood depth	0.05	m
	Eddy viscosity coefficient	0.28	/
	Manning coefficient	32	/
AD module	Horizontal diffusion coefficient	1.5	m^2/s
	Degradation coefficient of TP	0.00000018	/s
	Degradation coefficient of TN	0.000000012	/s
Eco Lab module	Temperature coefficient of respiration	1.07	/
	Respiratory semi-saturation number	2	mg/L
	Oxygen demand for degradation of sedimentary organic matter	0.1	$/(d \cdot m^2)$

3.1.2. Model Verification

In this study, the average relative error [12] (MAPE) was used to evaluate the calibration effect of model parameters, and its calculation equation is as follows.

$$\text{MAPE}= \frac{1}{n}\sum_{i=1}^{n}\left|\frac{X_i-Y_i}{Y_i}\times 100\%\right| \tag{1}$$

where X_i is the simulated value of the model; Y_i is the measured value; *n* represents the number of samples.

For the HD module, most studies show MAPE of less than 30%, indicating better simulation results [13, 14].

For AD and ECO-Lab modules, MAPE≤25% means excellent effect; 25%<MAPE≤40% means good effect; 40%<MAPE≤70% means average effect; MAPE>70% means that the results are not in line with the actual situation [15, 16].

(1) HD module verification: In the present study, the daily water level data of 11 stations (the spatial position of each section is shown in Figure 7) were used to verify the parameter calibration effect of the hydrodynamic module, and the results are shown in Table 2.

Figure 7. Spatial position of the section verified by the hydrodynamic module.

Table 2. Average relative error of water level simulation results.

Serial number	Station	Average relative error (%)
1	Taipingxi Hydrological Station	0.13
2	Maoping Hydrological Station	0.12
3	Yandu River Shibanping Hydrological Station	8.21
4	Wanxian Hydrological Station	0.45
5	Zhongxian Hydrological Station	0.52
6	Qingxichang Hydrological Station	0.76
7	Qijiang Wucha Hydrological Station	2.74
8	Cuntan Hydrological Station	3.42
9	Zhutuo Hydrological Station	4.87
10	Fengjie Hydrological Station	0.29
11	Wushan Hydrological Station	0.19

Table 2 told that the average relative errors of the simulation results of each section are all within 10%, and that of Taipingxi, Maoping, Wanxian, Zhongxian, Qingxichang, Fengjie and Wushan hydrological stations are all below 1%. In conclusion, the water level calibration results of the above 11 stations are excellent, and the parameter calibration results of the HD module meet the requirements.

(2) Verification of AD and ECO-Lab modules: The water quality module includes the AD module and ECO Lab module, and the parameters to be calibrated are mainly the degradation coefficients of TN, TP and DO.

In this study, the daily measured pollutant concentration data of 14 tributaries in the study area, Zhutuo section in the upper boundary and dam site in the lower boundary in 2018 were collected from the environmental protection department for simulation, and the measured pollutant concentration data at sections including Taipingxi, Wanzhou, Cuntan, Shaiwangba, Heshangshan, Baidicheng, Jiangjin Bridge, Lidu, Peishi, Qingxichang and Sujia (the spatial distribution is shown in Figure 8) were adopted for verification. The results are shown in Table 3.

Figure 8. Spatial distribution of verification sections.

Table 3. Average relative error of simulation results.

Station	Average relative error MAPE (%)		
	TN	TP	DO
Taipingxi	19.60	39.30	15.94
Wanzhou	10.44	28.30	10.23
Cuntan	22.73	25.70	8.91
Shaiwangba	11.43	22.55	9.84
Heshangshan	27.83	32.74	10.91
Baidicheng	21.55	34.82	17.03
Jiangjin Bridge	21.11	23.55	12.24
Lidu	18.64	28.08	11.47
Peishi	11.21	39.28	12.80
Qingxichang	20.48	23.07	10.56
Sujia	25.67	23.56	9.61

Above calculated results were compared with the measured values. It can be seen that the MAPE of TN is between 11.21% and 27.83%, and that of DO is in the range of 8.91%-17.03%. The simulation effect of TN and TP is better (relative error<30%). The MAPE of TP is between 22.55% and 39.30%. Although the relative error is slightly larger, the consistent variation trend indicated that the error is within the normal error range. The main reason for this situation is that the water environmental factors in the water body are complex and interact with each other, and the total phosphorus concentration data of sewage outlets and tributaries in the reservoir area cannot be fully counted at present, which cannot accurately reflect the changes of pollutant concentration. Overall, the simulation error of the model is good, which shows that the constructed water quality model can accurately simulate the changes in total phosphorus, total nitrogen and dissolved oxygen in the basin.

3.2. Annual Variation of Pollutants

In the present study, the daily scale data of total nitrogen, total phosphorus and dissolved oxygen concentrations at the inlets of Daning, Xiaojiang and Xiangxi River in 2021 were analyzed, and the results are shown in Figure 9.

As can be seen from Figure 9 above, for the three types of pollutants, the time variation characteristics of the inlet of the Daning, Xiangxi and Xiaojiang River are different.

In terms of total phosphorus, the concentration at the entrance of Daning, Xiaojiang and Xiangxi River varied greatly from May to August, and showed a peak value (Figure 9a). However, the variation range of monthly concentration is different, Xiangxi River>Daning River>Xiaojiang River. From January to May, the concentration in the inlet of Xiaojiang River and Daning River was relatively stable and maintained at a low value for a long time, while the concentration in Xiangxi River changed greatly and showed a maximum value. From June to December, although the variation trends of the three concentrations were similar, the concentration in the inlet of Xiangxi River still changed greatly.

In terms of total nitrogen, the variation trend of the concentration at the inlet of Xiaojiang, Daning and Xiangxi rivers was similar, with obvious fluctuations throughout the year (Figure 9b). However, from the perspective of monthly variation characteristics, the concentration of the Daning River inlet fluctuated the most violently, with many extreme values. Except for the maximum value in March, the fluctuation of the Xiangxi River inlet was close to that of the Xiaojiang River inlet in other periods, and the overall variation range was relatively small.

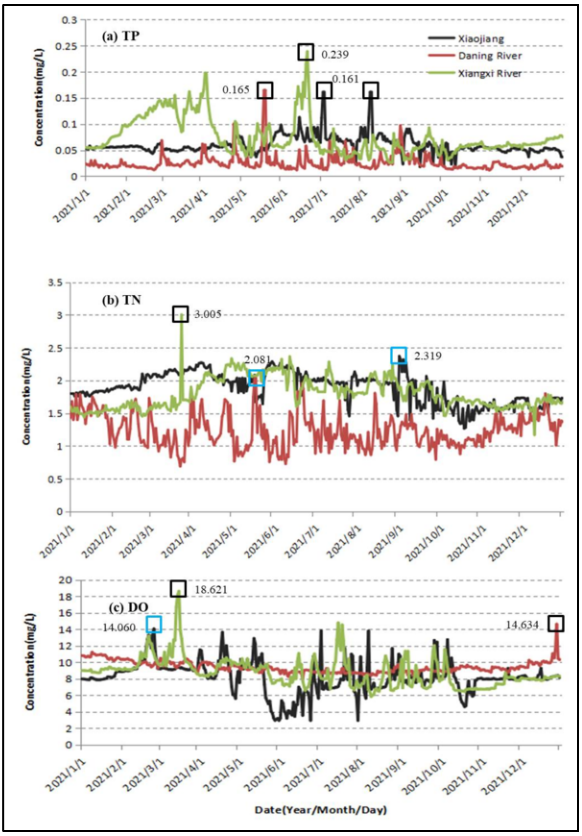


Figure 9. Total phosphorus, total nitrogen, dissolved oxygen concentration diagram.

The concentration of dissolved oxygen at the inlet of Daning, Xiaojiang and Xiangxi River decreased from January to July and increased from August to December (Figure 9c). However, the variation of the concentration within a month is quite different. Among them, the concentration at the inlet of Xiangxi River and Xiaojiang River fluctuates sharply, while the concentration at the inlet of Daning River shows a single trend.

In a word, the change characteristics of different pollutants on different sections are different. It can be seen that the pollution status in the water body is related to various factors such as pollutant type, section characteristics and hydrodynamic conditions, showing complexity and comprehensiveness.

3.3. Spatial Distribution of Pollutants

Since the measured data is limited by the number of observation stations, this study can show the annual variation trend of each pollutant index, but it is difficult to get the spatial distribution characteristics at the river reach and analyze the backwater area such as the tributary bays in depth. In order to further analyze the spatial distribution of pollutants in typical river sections, the hydrodynamic-water quality-water ecological coupling model constructed in the Three Gorges Reservoir area was used. Based on the calibrated parameters of each module, the spatial distribution characteristics of TN, TP and DO in Daning, Xiaojiang and Xiangxi rivers in the Three Gorges Reservoir area in 2021 were simulated. Besides, the simulation results at the end of August (the high incidence period of eutrophication) were selected for analysis.

From Figure 10a, on August 31st, the total nitrogen was concentrated in the typical reach, showing that the concentration at tributaries was higher than that at the main stream. However, from the local perspective, the concentration distribution characteristics of the three typical rivers are different. The total nitrogen of the Daning River is mainly distributed in the backwater area of the junction, while the spatial distribution of Xiaojiang River and Xiangxi River is similar, and the pollutants are mainly concentrated in the upper reaches, which is related to the characteristics of each river. In conclusion, the main stream has influence on the concentration distribution of total nitrogen in all tributaries, but the degree of influence is different.

The total phosphorus was mainly concentrated in the local part of the main stream and the backwater area of the tributaries (Figure 10b). From the upper reaches of the main stream to the lower reaches, the concentration is decreasing. Locally, the concentration of the three rivers varied, with the variation range being Daning River>Xiangxi River>Xiaojiang River.

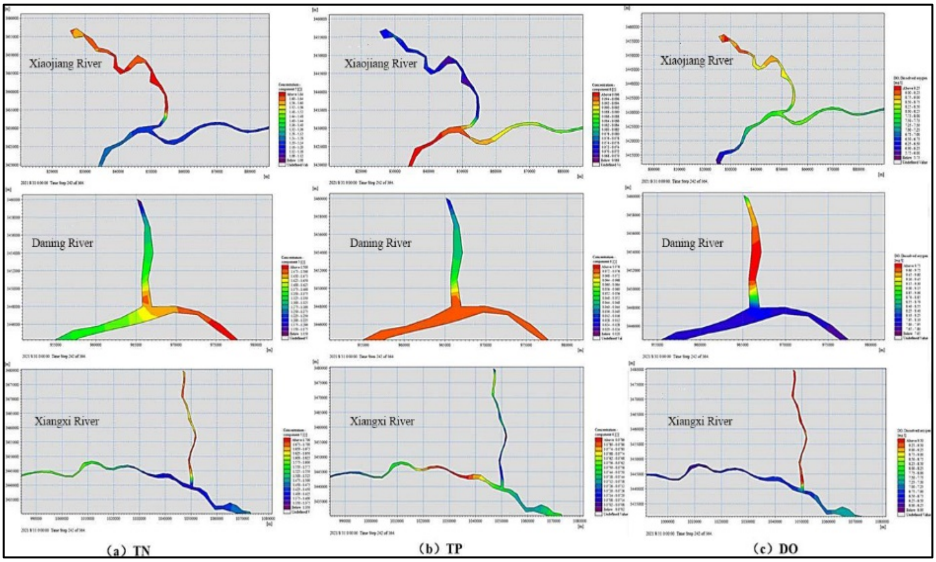


Figure 10. Spatial distribution of pollutant concentrations on August 31st.

The spatial distribution of dissolved oxygen concentration decreased from the upstream of the tributary to the inlet, while the concentration in the backwater and main stream was relatively low (Figure 10c). Among them, the concentration of the Xiaojiang River changes evenly with the spatial location, while the Daning River and

Xiangxi River have significant changes. This may be related to the morphology of rivers. The morphology of small rivers is more complicated and varied, which is conducive to eliminating the extreme concentration and making the changes more stable. The morphology of the Xiangxi and Daning River is relatively simple, and extreme concentration is more likely to appear.

In general, the concentration of pollutants in the main stream has a certain influence on the tributaries, but the degree of influence is different, which is related to the river form, hydrodynamic conditions, pollutant degradation status and other factors.

4. Discussion

From the point of view of hydrodynamics, the inlets of the Daning, Xiangxi and Xiaojiang River are all located in the area where the main stream of the Yangtze River and its tributaries exchange strongly, and the change of water level will inevitably affect the distribution characteristics of water quality. From the highstand period to the pre-discharge stage (January-June), the water level at the dam site of the Three Gorges Reservoir area was declining continuously, and the reservoirs of Daning River, Xiangxi River and Xiaojiang River were dominated by outflow, that is, some water bodies stranded in the reservoirs in the early stage were discharged from the reservoirs, mainly by natural discharge, which leads to the fluctuation of the TN and TP concentrations in the reservoirs. This result is basically consistent with the research conclusions of Han et al. [17]. From the post-discharge period to the lowstand period (July-August), the Three Gorges dam site was maintained at the lowstand period. At this time, the rainfall in the reservoir area was relatively large, and the surface runoff increased. Many pollutants flew into the river with the runoff, which leads to serious non-point source pollution, while the water levels in the inlets of Daning River, Xiangxi River and Xiaojiang River were low and the water volume was small. Under this condition, the concentration of TN and TP increased and peaked in late August and early September. This result is basically consistent with the research conclusions of Zhang et al. [18]. During the impoundment period (September-October), the water level at the dam site of the Three Gorges rose rapidly, and a considerable amount of backwater from the main stream flew backward into the reservoirs of Daning River, Xiangxi River and Xiaojiang River, resulting in an increase in water volume, which is conducive to the degradation of total nitrogen and total phosphorus. From November to December, the rainfall in the reservoir area decreased and the non-point source pollution decreased as well. The water level was still relatively high, that is, the water volume in the reservoir area was relatively large. Meanwhile, the sources of pollutants were restricted. Therefore, it is beneficial to the dilution and degradation of pollutants. In addition, the water flow slowed down, and the pollutants in the water settled with the sediment. During this process, the pollutants were stored in the sediment, thus purifying the water quality, which makes the concentration of TN and TP still show a downward trend during this period.

From the simulation results of the model, the backwater areas of the three typical tributaries are all with high total nitrogen, total phosphorus and dissolved oxygen concentrations. This phenomenon can be mainly explained from two aspects: (1) Pollution caused by human activities. The pollutants produced by human activities are collected in the backwater area with the flow of water. (2) The influence of hydrodynamic conditions. The hydrodynamic conditions in the confluence area of the main stream and tributaries are complicated, and the stratified backwater of the main stream of the Three Gorges will cause the enrichment of pollutants at the inlet. It is speculated that there may be a backward flow evolution model in the reservoirs and bays of Xiaojiang, Daning and Xiangxi rivers, which means that the mainstream of the Three Gorges flows backward from the middle or surface layer into the reservoirs and bays of Daning River from May to August, thus making the concentration of pollutants at the inlet increase. In addition, during this period, the water bodies at the junction of the main and tributaries exchanged fiercely, which led to an increase in dissolved oxygen concentration, which is consistent with the research conclusions of Liu et al. [19]. The hydrodynamic process is active, which is beneficial to oxygen dissolution [20]. The special simulation results indicated that the dissolved oxygen concentration in tributaries and backwater areas was high. In addition, the nutrients input from the upper reaches of tributaries stayed in the tributary bays, resulting in eutrophication of water bodies, frequent outbreaks of algal blooms, and changes in dissolved oxygen content in water bodies caused by life activities of algal blooms, which makes the dissolved oxygen in typical tributaries fluctuate in time. The result is consistent with that of Chen et al. [21].

The TP, TN and DO were selected for analysis in this paper, aiming at qualitatively reflecting the eutrophication status of water body through their changing laws. The concentration of TN and TP in the water body is an important evaluation index to reflect the nutritional characteristics of the water body. It has been suggested that the TN concentration of 0.2 mg/L and the TP concentration of 0.02 mg/L are the nutrient thresholds of water body eutrophication. According to the analysis results of measured data, in 2021, the c(TN) and c(TP) of the surface water bodies of Daning River, Xiangxi River and Xiaojiang Bay were all higher than 0, respectively. Among them, the concentrations of TP and TN peaked in spring and summer (March-August), and the water temperature was high at that time, which is beneficial to the rapid reproduction of algae and other plankton in the reservoir and eutrophication. Combined with the model simulation results, the algal bloom was more likely to break out in the tributary reservoir bay, which is consistent with the research conclusion of Zhou et al. [22]. In addition, the dissolved oxygen in Xiaojiang River and Xiangxi River showed a strong fluctuation change with a peak value, while that in Daning River was at a low level, so Xiaojiang River and Xiangxi River are more prone to eutrophication. Studies have shown that eutrophic water contains nitrite and nitrate, which will affect human and animal health. In order to mitigate eutrophication in the reservoir area, it is necessary to appropriately reduce the emission of nitrogen and phosphorus, such as controlling the emission of pollutants at the source, intercepting pollutants in the river, and building a pre-storage at the storage entrance.

5. Conclusions

(1) In this study, a MIKE 21 model was constructed according to the actual terrain conditions of the Three Gorges Reservoir area. The results show that the model can reflect the distribution of pollutants in the water body well, and the simulation results can provide a basis for improving the water quality of rivers;

(2) In July and August, when there is more rain, the concentration of pollutants fluctuated as a whole. With the increase in rainfall, the surface runoff increased, and many pollutants flew into the river accordingly, which caused the concentration of

pollutants in the backwater area to increase. Therefore, it is of great importance to take water environment control and ecological restoration measures for the tributaries; In spring and summer (March-August), the number of pollutants in the reservoir was large, the concentrations of TN and TP were high, and the temperature was high, so eutrophication was easy to occur, and algal blooms occurred in the reservoir bay area with relatively low flow rate;

(3) Based on the results of this study, appropriate measures should be taken to deal with the changes of pollutants in different time periods in the reservoir area, such as controlling exogenous pollution, and reducing endogenous pollution by dredging sediment. This paper has important reference value for water environment management and eutrophication assessment, and also provides a practical basis for related research.

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