Temporal and Spatial Distribution of Chlorophyll-a in Caotang River of Three Gorges Reservoir

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Abstract: To study the formation of algae blooms in Caotang River, a tributary of the Three Gorges Reservoir, the authors set up six monitoring sites in Caotang River and Yangtze River to continuously monitor the concentration of chlorophyll-a for one year from July 2017 to June 2018 and analyzed the distribution of algae blooms. It is found that in the vertical direction, chlorophyll-a had a maximum concentration at 2.41 mg/m³ at the surface and a minimum concentration of 0.69 mg/m³ at the bottom. The algae blooms broke out in Caotang River from July to September 2017, and there was no significant difference in the concentration of chlorophyll-a during other periods. During algae blooms, the concentration of chlorophyll-a increased from downstream to upstream except for the source section. There was no significant difference in the concentration of chlorophyll in the middle and bottom water bodies. The Yangtze River has a lower concentration of algal toxin than that in the Caotang River. Excluding the source where algal toxin was not observed, this study found that the concentrations of algal toxin in the other three sections (CT01, CT02 and CT03) were at 0.42 ug/L, 0.56 ug/L and 0.83 ug/L, respectively.

1. Introduction

Since the impoundment of the Three Gorges Reservoir, the natural river channel has been turned into a seasonal reservoir. Factors including the uplift of the Yangtze River, slower flow velocity of tributaries, sediment deposition, lower capacity of water diffusion, and prolonged residence time of pollutants have led to algae blooms[1-6]. In the past five years, algae blooms, in transformation from the dominant channel-based algae species (diatoms and dinoflagellates) to lake-based algae species (blue-green algae)[8], have occurred as many as 100 times in tributaries of the reservoir[7]. Some algae blooms (especially microcystis blooms) will produce algal toxin[9, 10], seriously affecting water safety of the Three Gorges Reservoir.

Located in the northeast of Chongqing and north of Qutang Gorge of the Yangtze River, the Caotang River originates from the junction of Fengjie County and Wuxi County and runs from northeast to southwest[11]. It flows into the Yangtze River under extremely complex hydrodynamic conditions[12]. The growth, accumulation and distribution of algae bloom are different from those of other tributaries. This study monitored the concentration of chlorophyll in Caotang River, a tributary of the reservoir area for one consecutive year for the purpose of analyzing the development of algae
bloom, serving as references for further exploration of the formation of algae bloom in the Three Gorges Reservoir.

2. Material and Method

2.1 Survey region
Caotang River is located 109°31’03’’E-109°45’20’’ E and 31°02’40’’N-31°10’06’’ N, covering Caotang, Baidi and Fenhe Sanxiang Town of the Fengjie County. It consists of Fenhe River and Shima River, with a total length of 33.3 km and a coverage of 394.8 km² which flows at an average annual rate of 7.51 m³/s and an annual runoff of 237 million m³[11,12]. The bank-up water level of the reservoir area reaches up to Zhuyi Caotang Town.

2.2 Setting up sampling sites
There were six sampling sites in this study. Among them, four sites were set up from the upstream to the downstream along the mid-stream line of the riverway, marked by CT04, CT03, CT02 and CT01, respectively. The other two sites, labeled as CTCJ01 and CTCJ02, were set up along the left bank of the Yangtze River in the upstream and downstream at the junction of Caotang River and the Yangtze River. The location of each monitoring point is shown in Figure 1 and Table 1.

![Sampling Site Layout and Coverage at Caotang River](image)

**Table 1. Coordinates of Each Sampling Site and Distance to Estuary**

| Points  | Location          | Distance from estuary (km) | Longitude (N)    | Latitude (E)     |
|---------|-------------------|----------------------------|------------------|------------------|
| CT01    | downstream(Caotang)| 0.50                       | 109°34'26.12"    | 31°2'52.5"       |
| CT02    | midstream(Caotang) | 3.5                        | 109°35'40.38"    | 31°3'17.05"      |
2.3 Monitoring time
The monitoring went from July 24, 2017 to June 30, 2018, which took place at the end of every month. Each tributary was monitored from top to bottom, starting at 8 a.m. The monitoring sequence was kept consistent during the investigation.

2.4 Monitoring method
In this study, chlorophyll-a, the indicator of algae bloom biomass, was determined by acetone extraction spectrophotometry\[13\] while algal toxin was measured by high performance liquid chromatography (HPLC)\[14\].

2.5 Data analysis
Chlorophyll-a and algal toxin at each site were monitored three times, and the average value was taken as the concentration of chlorophyll and algal toxin at the site.

3. Result and Analysis

3.1 Distribution of chlorophyll-a
The vertical concentration of chlorophyll-a was generally characterized by surface \(>\) middle \(>\) bottom layer in both Yangtze River and the Caotang River, suggesting that algae bloom cells mainly concentrated in the surface of the water body, which may be the result of photosynthesis of algal cells in the upper surface that rapidly grew into the dominant algal species. As to the concentration of chlorophyll-a throughout the year, CT03 had the highest concentration of 2.41 mg/m³ in the surface layer, while CT04 had the lowest concentration of 1.33 mg/m³. CT02 had a relatively high concentration of 1.06 mg/m³ in the middle layer. The two sections CTCJ01 and CTCJ02 at the junction of Yangtze river and Caotang River had a significantly lower concentration of chlorophyll-a in the surface layer than sections of the Caotang River, indicating that the density of algae cells in the Yangtze river was lower than that of the Caotang River. This is probably because the Yangtze River's dry water power is not conducive to the growth of aquatic plants, while the Caotang River's slow flow speed is conducive to the growth of algae.

| Points          | Surface Layer | Middle Layer | Bottom Layer |
|-----------------|---------------|--------------|--------------|
| CT01            | 2.09±6.06     | 0.94±1.71    | 1.00±0.65    |
| CT02            | 2.34±5.11     | 1.06±0.99    | 1.05±0.73    |
| CT03            | 2.41±7.69     | 0.88±0.98    | 0.69±0.42    |

Table 2. Mean and Standard Deviation of Chlorophyll-a Variation (mg/m³)
In terms of time progress, the concentration of chlorophyll-a in the Caotang River showed an explosive increase from July 2017. In August, the concentration in the upper layer of CT03 section reached 19.56 mg/L. However, in September, the concentration of upper water body decreased sharply, which was most likely caused by algae bloom in the Caotang River in August. Except for section CT04 at the source, the concentration of chlorophyll-a in the upper layer was ranked CT03 > CT02 > CT01, which gradually increased from the lower reaches to the upper stream. In the middle and bottom water bodies of Caotang River and Yangtze River, there was no significant difference in the concentration of chlorophyll-a. Except for October 2017 during which the concentration of chlorophyll-a in the middle water body of CT03 was 3.12 mg/m³, the concentration was lower than 3 mg/m³ in other periods. The distribution of chlorophyll-a in the Yangtze River and Caotang River showed that algae blooms mainly concentrated at the end of the backwater area of Caotang River, probably caused by the convergence of Caotang River and Yangtze River, in which the surface water body flows backward into Caotang River from the Yangtze River, while the middle and lower water bodies flow into the Yangtze River from Caotang River. The complicated hydrodynamic conditions of the main and tributaries in the Three Gorges Reservoir are also verified in Xiangxi River, Shennongxi River and Daning River[23,15-16].

| Section | Chlorophyll-a Concentration |
|---------|-----------------------------|
| CT04    | 1.33±0.11                   |
| CTCJ01  | 1.04±1.55                   |
|         | 0.87±0.43                   |
|         | 0.53±0.41                   |
| CTCJ02  | 1.02±1.01                   |
|         | 1.25±0.22                   |
|         | 0.58±0.90                   |
According to OECD single factor (Chl-a) evaluation standard (where Chl-a<3 mg/m³ means poor nutrition; 3≤Chl-a<11 mg/m³ indicates medium nutrition; 11≤Chl-a<78 mg/m³ means eutrophication; Chl-a≥78mg/m³ means severe eutrophication) [17], the water body in the backwater area of Caotang River was in medium nutrition, while the other water bodies were in a poor nutrition. From November 2017 to June 2018, both the Caotang River and the Yangtze River were in poor nutrition.

3.2 Concentration of algal toxin

Algae toxin was detected in both the Yangtze and Caotang rivers. However, the Yangtze River had a lower concentration of algae toxin than that in the Caotang River (Table 3), probably because the hydrological and hydrodynamic conditions in the Yangtze River were not conducive to the growth of algal cells compared with the Caotang River. CT04 was the only section where no algal toxin was detected, while the other three sections of CT01, CT02 and CT03 were found with a concentration of 0.42 ug/L, 0.56 ug/L and 0.83 ug/L respectively, increasing from downstream to upstream. The distribution of algal toxin in the Caotang River may be affected by the backing power from water bodies of the Yangtze River during impoundment at the Three Gorges Reservoir from July to September, where algae blooms gathered to the upstream of the reservoir, thus increasing the concentration of algal toxin.
Table 3. Concentration of Algal Toxin at Each Monitoring Section (ug/L)

| Piobnts | CTCJ01 | CTCJ02 | CT01 | CT02 | CT03 | CT04 |
|---------|--------|--------|------|------|------|------|
| Algae toxin Concentration | 0.39 | 0.35 | 0.42 | 0.56 | 0.83 | 0 |

Previous studies showed that algae blooms mainly occurred at the end of tributary's backwater area in the Three Gorges Reservoir\(^{[6]}\). In this study, algae blooms and algal toxin was detected at the end of the Caotang River's backwater area. Algal toxin was mainly caused by cyanobacteria algae blooms, suggesting the role cyanobacteria cells as the dominant algal species. At present, algae blooms in the Three Gorges Reservoir are mainly caused by green algae and diatoms\(^{[18]}\). However, the cyanobacteria algae blooms were detected at the end of the Caotang River's backwater area, indicating the diversity of algae blooms in tributaries of the Three Gorges Reservoir.

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