



# The New Situation of Diatom Bloom in the Middle and Lower Reaches of Hanjiang River under River Chief System

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**Abstract.** In the middle and lower reaches of the Hanjiang River in February 2018, another serious diatom bloom occurred. The Changjiang Water Resources Commission promptly initiated an emergency plan to use the cascade reservoirs at the middle and lower reaches of the Hanjiang River to carry out water scheduling. At the same time, six monitoring sections were set up to daily monitor in the middle and lower reaches of the Hanjiang River. From 9 February to 18 March, this bloom had lasted more than 30 d. It is the longest since the record was recorded. The emergency dispatch measures adopted during the outbreak of the diatom bloom have stopped the further development of diatom bloom and played a good role. Analysing the causes of diatom bloom can provide a more comprehensive basis for further optimizing emergency dispatch. This paper analyzes the key hydrological factors that occur in this diatom bloom and proposes a water dispatching optimization plan and specific countermeasures. However, to permanently solve the diatom bloom problem, it is necessary for local environmental protection departments to work actively under the current requirements of the river chief system. Comprehensive protection of the Hanjiang River water ecological environment, completely solve the watershed problem of non-point source pollution.

## 1 Introduction

Under the current background where the river chief system is fully promoted, local governments at each level pay a lot of attention to the water environment issue in the regions under their jurisdiction. Particularly at the boundaries of administrative regions, the environment issue of water systems, rivers and lakes has become a focus of attention from each concerned party. Hanjiang is the largest tributary of the Yangtze River. Danjiangkou reservoir at the middle reach is a water source for the middle line of the south-to-north water transfer project, shouldering the heavy responsibility for easing the water consumption pressure of the north of China. The mainstream of the middle and lower reaches flow past 14 cities, which is also an important source of water consumption for

industry, agricultural and the life of residents in Shaanxi and Hubei. However, in recent years, eutrophication has escalated in the water bodies of the middle and lower reaches of Hanjiang River, and diatom bloom has occurred frequently (Dou et al., 2002). Since the first large-scale outbreak of diatom bloom in the spring of 1992, it would cause a heavy impact to the ecological environment of water bodies along the river every other year. Particularly after 2010, diatom bloom has broken out more frequently and showed a trend of gradual expansion, which has seriously threatened the ecological safety of the region and caused a big challenge to the implementation of river chief system (Zhang et al., 2016).

As a typical example of river algae bloom, the algae bloom of Hanjiang River is in substance diatom bloom. Unlike blue and green algae bloom in still-water ecological systems such

as lakes and reservoirs, most algae bloom is highly resistant to a low temperature and prefers a water body with a certain flowing speed. They have a certain demand for nutritive salt such as nitrogen and phosphorus, they synthesize cell walls with the silicate in the environment. Therefore, the content of silicon is a critical factor influencing the growth of diatom. All these are the preconditions for the occurrence of diatom bloom in Hanjiang River under specific seasonal (spring) and hydrological conditions (dry season). Relevant research findings have been achieved in China and abroad on the cause and biological mechanism of diatom bloom. Most researchers argue that the diatom bloom is caused by a high level of nutritional salt and appropriate weather and hydrological conditions. However, diatom bloom is diversified and occurs in a wide spectrum of ecological environment, diatom bloom may be caused by different factors in different ecological systems. For example, most researchers the river diatom bloom can be attributed to a low flowing speed, a high level of nutritional salt and an appropriate temperature (Pan et al., 2014). However, some scholars point out, the building of large water conservancy projects, particularly dams, has a significant impact to the structure of plankton in the rivers (Xie et al., 2005; Li et al., 2016). Xie et al. point out that water quality factors such as nitrogen and phosphorus and climatic factors such as water temperature are not the critical factors to restrict the occurrence of diatom bloom in Hanjiang River. Hydrological factors such as flow and speed under the influence of water conservancy projects are the very critical factors (Xie et al., 2004).

An analysis of latest research fruits reveals that a consensus has been reached on diatom bloom, namely, physical factors such as precipitation and temperature are usually more important than factors such as the level of nutritional salt in the water body. Hydrological factors are very probably the limiting factors in the outbreak of diatom bloom (Ren et al., 2017). Based on the theory, Changjiang Water Resources Commission, an administration body of the river, has ever tackled the diatom bloom of Hanjiang River by regulating the cascaded reservoir in the middle and lower reaches of Hanjiang River, which used to achieve a good effect. However, viewed from the latest outbreak of diatom bloom in February 2018, the situation of diatom bloom in Hanjiang River was recorded with some new changes. As a result, the effect of tackling diatom bloom with the same method was not so good. This paper will make a detailed analysis of the new situation around the outbreak of diatom bloom in Hanjiang River, put forward new solutions to the new problem and provide a scientific reference for actively promoting the river chief system and the prevention and control of diatom bloom in Hanjiang River.

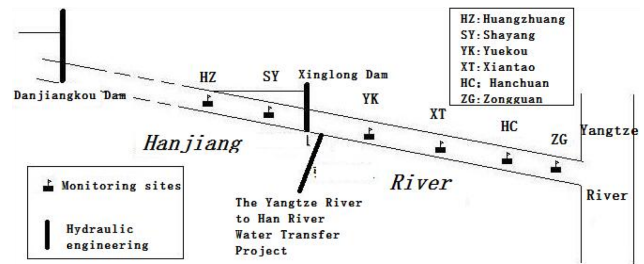


Figure 1. Layout of Emergency Monitoring Cross Sections.

## 2 The Outbreak Process of Diatom bloom in Hanjiang River in 2018

In the first third of February 2018, the staff of hydrometric stations along the river found abnormality in the water body in the middle and lower reaches of Hanjiang River, which seemed diatom bloom. It was verified after the environment protection staff monitored the site that starting from 9 February, a slight diatom bloom occurred in the section of Hanjiang River below Huangzhuang station. The water color of the river section showed abnormality and became increasingly dark. By 11 February, the water color became darker and turned brown, accompanied by a strong stench. Based on these phenomena, they judged that Hanjiang River had been hit by another outbreak of diatom bloom. To guarantee the water safety for urban and rural residents at the middle and lower reaches of Hanjiang River, Changjiang Water Resources Commission launched a contingency plan, increased the discharged volume of cascaded reservoirs to regulate the flow and carried out a daily monitoring on the algae in the section ranging from Huangzhuang to Wuhan (about 400 km) in the middle and lower reaches of Hanjiang River. By around 9 March, the diatom bloom of the entire river section faded away significantly, the water color changed from brown to light green. By far, the diatom bloom had lasted for more than 30 d which was recorded as the longest one in the history.

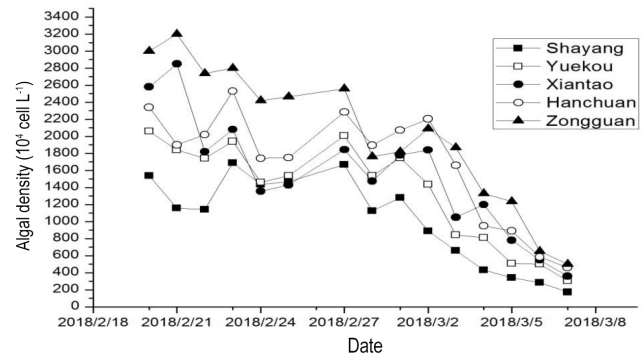
The monitoring set six sections, including Huangzhuang, Shayang, Yuekou, Xiantao, Hanchuan and Zongguan (the positions of the sections are shown in Fig. 1), of which Huangzhuang represents the inlet section of Xinglong reservoir, Shayang is the cross section of Xinglong reservoir, Yuekou, Xiantao, Hanchuan are respectively the cross sections of the river at the lower reach of Xinglong dam, while Zongguan represents the cross sections of the estuary at the lowest reach of Hanjiang River. The monitoring parameters of the cross sections include water temperature, pH, dissolved oxygen, saturation degree, chlorophyll a, algal density, dominant species of algae and corresponding hydrological parameters.

According to the monitoring results, after the outbreak of diatom bloom, Changjiang Water Resources Commission immediately launched a contingency plan to increase the

discharged volume of water control projects such as Danjiangkou, Cuijiaying and Xinglong, increase the flow of the lower reaches and eliminate the key hydrological factors causing the diatom bloom. From 12 to 22 February, the flow of Huangzhuang station fluctuated at  $834\text{--}962\text{ m}^3\text{ s}^{-1}$ , the flow of Xinglong station fluctuated at  $648\text{--}890\text{ m}^3\text{ s}^{-1}$ , the flow of Xiantao station fluctuated at  $834\text{--}962\text{ m}^3\text{ s}^{-1}$  and the average flowing speed at the cross section of Huangzhuang and Shayang fluctuated at  $0.4\text{--}0.5\text{ m s}^{-1}$ , and the flow speed of Xinglong and Xiantao stations fluctuated at  $0.6\text{--}0.8\text{ m s}^{-1}$ . The minimal water temperature of each monitored cross section during the outbreak of diatom bloom was  $8.5^\circ$ , and the maximum temperature was  $17.7^\circ$ . The average temperature of Shayang cross section was  $10^\circ$ , the average temperature of Xiantao cross section was  $11^\circ$ , the average temperature of Zongguan cross section was  $12.6^\circ$ . The pH value rose from 8.1 to 8.9, the changing range of dissolved oxygen was  $9.71\text{--}15.7\text{ mg L}^{-1}$ . The saturation degree had once risen to 151%. The above parameters had surpassed the warning values for the outbreak of diatom bloom (water temperature  $\geq 10^\circ$ ,  $\text{pH} \geq 8.0$ ,  $\text{DO} \geq 12\text{ mg L}^{-1}$ ) (Lu et al., 2000). This indicates that the outbreak of diatom bloom was serious in Hanjiang River. According to the monitoring of algal density in each cross section (Fig. 2), the extreme point of the outbreak of diatom bloom appeared around 21 February, near 10 d after its outbreak. The algal density of Zongguan cross section at the lower reach estuary of Hanjiang River reached 32 million cells per litre, which later began to decline, but the decline was slight. By 5 March, the algal density began to decline significantly. By 7 March, the algal density in each cross section had declined to around 5 million cells per litre. Meanwhile, the dominant species of algae monitored at Huangzhuang cross section changed from diatom to diatom and green algae, which indicated that diatom began to die and the new algal species took the dominant position. Diatom bloom began to fade away. By 9 March, the water color at each cross section under monitoring became increasingly normal, and the algal density at each cross section was around  $1.40\text{--}3.20$  million cells per litre.

### 3 Causal Analysis of Diatom bloom

In the earlier causal analysis of the diatom bloom in Hanjiang River, most researchers mainly focus on three areas. The first one is the water quality factors. The discharge of pollutants became increasingly serious in the middle and lower reaches of Hanjiang River. There were excessive nutritional salts such as nitrogen and phosphorus needed for the growth of algae. The Second one is the climatic factors. The warmth of spring and appropriate sunshine facilitated the mass propagation of algae. The third one is hydrological factors. Due to the high-level backwater effect of the Yangtze River and the decrease of the flow volume of Hanjiang River, the flowing speed of Hanjiang has slowed down. As a result, the water



**Figure 2.** The tendency chart of algal density in each cross section during the outbreak of diatom bloom.

body of Hanjiang River shows the characteristics of a lake, which provides an environment for the occurring of diatom bloom (Wang et al., 2004). However, compared with past formation conditions, new situations had appeared this time.

1. *The scope of the outbreak of diatom bloom had expanded.* The previous outbreaks of diatom bloom were mainly concentrated in the section ranging from Xiantao to Wuhan. The scope of influence mainly covered the areas 200 km from the estuary. The outbreak of diatom bloom this time had extended to Huangzhuang cross section, which was about 400 km from the estuary of the river. During the outbreak of diatom bloom, the algal density monitored at Shayang cross section in Xinglong reservoir reached 17 million cells per litre. This indicated that the outbreak of diatom bloom had extended to Xinglong reservoir.
2. *Washed by mass flows, the diatom bloom had not faded away for a long period.* Many previous researches of diatom bloom indicate that when the flow at the cross section of Xiantao is above  $500\text{ m}^3\text{ s}^{-1}$ , the diatom bloom will fade away gradually. Yin et al. have found by analyzing historical data that the diatom bloom could be solved when the flow volume of Xiantao station was higher than  $800\text{ m}^3\text{ s}^{-1}$  and the corresponding assurance rate reached 90% by regulating the water volumes of reservoirs (Yin et al., 2017). However, from the early stage of the outbreak of diatom bloom this time, the discharged volume of reservoirs like Danjiangkou and Xinglong was increased, the flow volume of Xiantao station remained above  $800\text{ m}^3\text{ s}^{-1}$  and even reached  $1230\text{ m}^3\text{ s}^{-1}$  at the maximum. However, the diatom bloom still did not fade away.

In the face of such a situation, we have concluded the following causes based on the analysis of monitoring data gained during the outbreak of diatom bloom and our historical experience.

1. *The issues concerning the dominant species of diatom.* All the time, cyclotella has been studied as the dominant species of diatom in the diatom bloom of Hanjiang River (Kuang et al., 2000). However, some scholars like Zheng Lingling and Yang Qiang have discovered by scanning with an electronic microscope that the dominant species in the diatom bloom of Hanjiang River is *Stephanodiscus* (Yang et al., 2011; Zheng, 2005). Though the two kinds of algae both belong to diatom, their living habits are different to a certain extent. For example, the former prefers an environment of still water and abundant phosphorus, while it is easier for the latter to dominate in an environment with a great disturbance to water body, with a certain flowing speed and a big fluctuation of the concentration of nutritional salt. Therefore, inferred from the facts such as algae still dominated as water from the upstream kept increasing, the dominant algal species was most likely to be *Stephanodiscus* rather than cyclotella.
2. *The issues concerning the control of pollution source.* Diatom bloom was identified at the Huangzhuang cross section at the inlet end of Xinglong reservoir, which indicated that the diatom bloom this year has extended to Xinglong reservoir. This means that the eutrophication was increasingly intensified at Xinglong reservoir. The water body flew out of Danjiangkou reservoir and past Xiangyang. At the cross section of Yujiahu, it showed a rise to a certain extent in the level of ammonia nitrogen and nitrate nitrogen. This indicated that the water body of Xinglong reservoir took in part of pollutants from the upstream, which included the pollutants discharged from upstream cities like Xiangyang. The level of nitrogen and phosphorus was also found to rise gradually at Xiantao and Jijiazui (estuary). This indicated that the water bodies at the middle and lower reaches of Hanjiang River were being attacked by the pollution along the river. The pollution control on both banks along the river was a daunting task. By comparing the N/P ratio at the monitored cross sections, we find that the N/P ratio at Xiantao and Jijiazui was closer to the threshold value suitable for the propagation of algae (N/P ratio = 13) (Wang, 2010), while the N/P ratio at Yujiahu cross section reached 86, far higher than the range suitable for algae. This also explained why no diatom bloom had occurred near the river section of Xiangyang.
3. *Special hydrological and weather situations.* By analyzing the changing trend of algal density at each monitored cross section in Fig. 2, we know that the algal density of each monitored showed a trend of gradual rising from the upstream Shayang to Zongguan near the estuary, showing a phenomenon of “time lag” in the spatial and temporal distribution, which was mainly because other than enduring its own algal propagation, the downstream river section also needed to receive

the algae washed down from the upstream and showed a state of accumulation. Meanwhile, affected by the weather, the propagation capacity of algae also fluctuated, which is another aspect of the “time lag”. For example, after the rainfall on 20 February, the algal density at each cross section declined to different extents on 21 and 22 February. Later, as the weather became fine, the algal density was rising again. This indicates that the weather, particularly sunshine, plays an important role in the eruption of diatom bloom. The changing trend of diatom bloom at each monitored cross section shown in Fig. 2 indicates that from 20 February to around 2 March, the algal density at the cross sections below Xinglong was declining, which may be because the result of water volume regulation had checked the further eruption of algae to a certain extent. However, in the same period the algal density at Shayang cross section had risen. Therefore, we need to analyze why the water volume regulation effect was not distinct at its upstream Danjiangkou. By analyzing relevant hydrology monitoring data, we find that taking 3 March as an example, the cross-section flow volume of Huangzhuang and Shayang stations in the same period was both  $1100 \text{ m}^3 \text{ s}^{-1}$ . However, the existence of Xinglong reservoir had significantly “weakened” the scour effect of water volume from upstream, which had also provided a buffer space for the propagation of algae in the reservoir. Therefore, we can infer that the main reason for the lasting of diatom bloom this time was mainly that the diatom bloom in Xinglong reservoir had not been effectively controlled. As Xinglong water control project increased discharged volume, it constantly sent algae to the downstream of the dam. As a result, at the macro level, the water volume regulation effect of Danjiangkou was not distinct.

4. *Other reasons.* The above three aspects may be the main reasons for the outbreak of diatom bloom this time surpassed the expectation. In addition, the backwater effect of the Yangtze River and the significant drop of silt level at the middle and lower reaches of Hanjiang River may have also stimulated the outbreak of the diatom bloom. By looking up water level and flow volume data of Hankou hydrology station during the outbreak of diatom bloom, we find that the water level of Wuhan section of the Yangtze River was higher than the same period of past years. Taking the hydrology condition of Hankou station on 10 February as an example, the average flow volume of cross section on the day was  $15\,100 \text{ m}^3 \text{ s}^{-1}$ , which increased near 50% than the average flow volume of February of past years (about  $10\,000 \text{ m}^3 \text{ s}^{-1}$ ). This indicates that the backwater effect of Yangtze River had reduced the water surface drop of the middle and lower reaches of Hanjiang River, which reduced the water surface flow speed to a certain extent and was also a

**Table 1.** Monitoring results of nutritional salts of some cross sections in the middle and lower reaches of Hanjiang River during February.

Cross section	Ammonia nitrogen (mg L <sup>-1</sup> )	Nitrate nitrogen (mg L <sup>-1</sup> )	Total nitrogen (mg L <sup>-1</sup> )	Total phosphorus (mg L <sup>-1</sup> )	Nitrogen / phosphorus ratio (mg L <sup>-1</sup> )
Below Danjiangkou dam	0.09	1.24	1.44	0.03	48
Yujiahu	0.12	1.60	1.72	0.02	86
Xiantao	0.01	1.76	1.77	0.09	19
Jijiazui	0.21	1.68	1.89	0.10	18

factor affecting the outbreak of diatom bloom. In addition, the issue of silts in Hanjiang River. With the establishment of water surface flow speed of cascaded reservoirs, the silt level in the water bodies in the lower reach became increasingly low. Analyzed from the physiological characteristics of algae, this would amplify the role played by sunshine in the propagation of algae. The silicon shell at the surface of diatom is relatively heavy, they are generally suspending at the middle and lower levels of the water body, which hinder their photosynthesis and growth. However, with the decreasing of silt, sunshine is easier to penetrate the water body, providing more sunshine for the growth of algae. As a result, it was easier to result in an outbreak of diatom bloom under the same weather conditions.

#### 4 Countermeasures under River Chief System

By analyzing the main causes of the outbreak of diatom bloom this time, the paper will put forward the following countermeasures.

##### 4.1 Strict control of pollution input

The serious eutrophication in the middle and lower reaches of Hanjiang River is the fundamental cause for the outbreak of diatom bloom. At present, the nitrogen and phosphorus level in the water body at the middle and lower reaches of Hanjiang River is high, which fully satisfies the necessary conditions for the formation of diatom bloom. The further extension of diatom bloom scope this year indicates that the pollution prevention and control needs to be further intensified for the middle and lower reaches of Hanjiang River. Particularly under the promotion of river chief system, each prefecture city along the river should pay full attention to the pollution control within the reach, prevent industrial and agricultural waste water and sanitary sewage, etc. that fail to reach the standard from being discharged into the river and gradually enhance the prevention and control capacity against the pollution source. Only by improving the overall water ecology environment of Hanjiang River is the fundamental method to permanently prevent the occurrence of diatom bloom in Hanjiang River.

##### 4.2 Optimizing water volume regulation scheme

Through co-regulation of reservoirs, the regulation of ecological flow volume is an emergency measure for preventing and control of diatom bloom in Hanjiang River. The purpose of ecological regulation is to eliminate the hydrological conditions for formation of diatom bloom and prevent the occurrence of diatom bloom. The emergency regulation this time tells us that in the future we should further optimize the regulating scheme, particularly during the sensitive period before outbreak of diatom bloom. If there is any sign of diatom bloom in Xinglong reservoir, first of all we should increase the discharged volume of Xinglong to reduce the water level of the reservoir, increase the water surface flow speed of the reservoir and the reach downstream the dam, to control the overall hydrological environment for propagation of algae. Then we should increase the discharged volume of Danjiangkou to further increase the water surface flow speed of the reservoir, replenish the water volume of the reservoir and dilute the algal density. Meanwhile, on the basis of guaranteeing other water demands, at the mainstream of Yangtze River we can reduce the discharged volume of the Three Gorges reservoirs, reduce the water level of the mainstream of Yangtze River at the estuary of Hanjiang River, to increase the flow speed at the middle and lower reaches of Hanjiang River and eliminate the influence of backwater from Yangtze River. Viewed from the experience of water volume regulation this time, the too early increase of discharged flow volume of Danjiangkou will do limited help to the prevention and control of diatom bloom and even waste the precious water source for South-to-north water diversion. In addition, considering that the eutrophication of Xinglong reservoir is increasingly serious, the daily frequency of water renewal of the reservoir needs to be increased. Calculated by a designed capacity of Xinglong reservoir at 485 million m<sup>3</sup>, if the water were discharged by a flow volume of 800 m<sup>3</sup> s<sup>-1</sup> at the time of emergent regulation, it will at least take around 1 week, which is extremely adverse to the control of algae during the outbreak of diatom bloom.

##### 4.3 Improve management mechanism

Considering that the water environment protection of Hanjiang River is a long-term task, and the ecological environ-

ment in Hanjiang River concerns the pursuit of a good life by about 40 million people of 78 counties and cities in 20 regions of six provinces along the river, we should actively improve related management mechanism, strengthen unified management of water volume and quality of Hanjiang River, and intensify the coordination, guidance, supervision and monitoring of organizations along the river, so as to build an ecological good environment as soon as possible.

## 5 Conclusion

1. The diatom bloom of Hanjiang River had lasted more than 30 d, which was the longest one in the history of records. The influencing scope of diatom bloom had extended from the original section from Wuhan to Xiantao to Xinglong reservoir and the situation of diatom bloom has witnessed new changes. By tracking and monitoring the diatom bloom this time, we can infer that the advantaged species of the diatom bloom may be *Stephionidiscus*. The maximum algal density during the outbreak of diatom bloom reached 32 million cells per litre. By comparing with the conventional threshold value of diatom bloom occurrence (algal density at  $10^5$  cells per litre), the water condition had basically restored normal when the algal density in the diatom bloom this time was  $10^6$  cells per litre.
2. The emergency regulation measure taken by Changjiang Water Resources Commission during the outbreak of diatom bloom has obviously checked the further escalation of diatom bloom to a certain extent. However, with the changing of situation, the regulation effect this time was not ideal compared with previous years, which brought new inspirations and new requirements for the emergency regulation work.
3. The fundamental cause of the diatom bloom was the eutrophication of the water body at the middle and lower reaches of Hanjiang River. Therefore, under the present situation, we should take the full implementation of river chief system as a chance to strictly control the pollution input, strengthen the prevention and control capacity against the pollution, improve the water ecology environment. As an emergency measure during the outbreak of diatom bloom, the water volume regulation needs to be gradually optimized and improved along with the changing environmental issues, so as to enhance the coordination, guidance, supervision and monitoring of the organizations in the river chief system.

**Data availability.** Data used to produce Fig. 2 is available in the Supplement.

**Supplement.** The supplement related to this article is available online at: <https://doi.org/10.5194/piahs-383-121-2020-supplement>.

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