

Impact of Cyanobacterial Bloom in Hulun Lake and Its Control Measures

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Abstract Firstly, the occurrence characteristics of cyanobacterial bloom in Hulun Lake were analyzed. Then, based on the data of daily average temperature and wind speed in Manzhouli and New Barag Right Banner from 2020 to 2025, the meteorological conditions suitable for the outbreak of cyanobacterial bloom were analyzed, and the temporal and spatial distribution characteristics of cyanobacterial bloom in Hulun Lake under remote sensing monitoring were further verified. Finally, measures for controlling cyanobacterial bloom were proposed.

Key words Cyanobacterial bloom; Outbreak characteristics; Temperature; Wind speed; Hulun Lake

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Algal bloom is an ecological phenomenon caused by the massive proliferation of algae such as green algae and diatoms as well as cyanobacteria triggered by the eutrophication of freshwater or marine water body. Among them, cyanobacterial bloom is the most common type of algal bloom. Cyanobacterial bloom usually occurs when blue-green algae multiply rapidly in eutrophic water body within a short period of time, and a "floating film" is formed on the water surface. If the eutrophication of water body cannot be effectively controlled, cyanobacterial bloom will recur periodically, thereby leading to the deterioration of the ecological environment. Regarding the influencing factors of outbreaks of cyanobacterial bloom, scholars have proposed various hypotheses such as the ratio of total nitrogen and total phosphorus, trace elements, rising water temperature, and predation by zooplankton, and have conducted relevant verification. Current extensive empirical studies have shown that climate change will affect the reproduction and survival of marine organisms. That is, when phytoplankton are affected by climate change, they will change, which corresponds to the hypothesis of rising water temperature. This indicates that the occurrence probability and intensity of algal blooms, especially harmful algal blooms, are increasing along with climate change, and their harmfulness is also constantly increasing.

Hulun Lake is located in the west of the Hulunbuir grassland in Inner Mongolia Autonomous Region. It is the fifth largest lake in China and the largest lake in the north, and has characteristics of both inland and exorheic lakes. The renewal cycle of water body lasts for 30 years, and the evaporation is much greater than the

precipitation. The lake water is rich in nitrogen, phosphorus, and other substances, and has been in a moderately eutrophic state for a long time, providing favorable conditions for the proliferation and development of algae. Climate factors such as water temperature and light become the dominant causes of cyanobacterial bloom, and the unreasonable structure of aquatic organisms and poor self-repair function further exacerbate the occurrence of cyanobacterial bloom. In this paper, the occurrence characteristics of cyanobacterial bloom in Hulun Lake were analyzed, and the influence of climate factors on cyanobacterial bloom was discussed. Moreover, measures for the control of cyanobacterial bloom in Hulun Lake were proposed.

1 Characteristics of cyanobacterial bloom in Hulun Lake

Hulun Lake is one of the five major freshwater lakes in China and the largest lake in Inner Mongolia. It is an important part of the ecological barrier in northern China, and plays a crucial ecological role in regulating climate, conserving water sources, preventing and controlling desertification, and maintaining the balance of the surrounding grassland ecosystem^[1]. The water area of Hulun Lake is vast, but the lake surface is an irregular oblique rectangle. The main sources of water replenishment for the lake are atmospheric precipitation and the inflow of water from the Kelulun River, Wu'eroxun River, and Dalan'eluomu River. There are approximately 80 rivers of various sizes within the water system of Hulun Lake. Due to various factors, the range of Hulun Lake has expanded and contracted several times. In the early 20th century, it turned into a complete inland depression and discontinuous small lakes. According to the measurement record on December 25, 2024, the water volume of Hulun Lake is 13.790 billion m³, and the area of the water surface is 2 241.60 km². Hulun Lake

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has a temperate semi-arid continental climate, with distinct seasons. Spring is windy and has less rainfall; summer is cool and short; temperature drops rapidly in autumn; winter is cold and long. The annual average temperature is 9.6 °C, and the annual average precipitation is 256.7 mm. The annual average evaporation is more than 6 times that of precipitation, reaching 1 634.1 mm. The annual average wind speed is 3.3 m/s. The freeze period of Hulun Lake lasts for 170 – 180 d each year, and cyanobacterial bloom occurs from June to September.

Since the 1990s, Hulun Lake has suffered from cyanobacterial bloom. In 1936, the water of Hulun Lake turned green due to *Microcystis aeruginosa*. According to the data of remote sensing images from June to August in Hulun Lake during 2013 – 2023, it can be seen that cyanobacterial bloom happened in Hulun Lake every year over the past 11 years. Except for 2014, 2016, and 2019 without severe cyanobacterial bloom, cyanobacterial bloom was severe in other years. Among them, cyanobacterial bloom was the most severe in 2022, with an average frequency of 5.3. In 2013, the annual average frequency of cyanobacterial bloom was the second, up to 1.0. In 2021, the average frequency of cyanobacterial bloom was low, only 0.7. In 2016, the annual average frequency of cyanobacterial bloom was the lowest. During a year, the cyanobacterial bloom in Hulun Lake usually occurred from June to August, and in most years, it was concentrated from middle July to middle August. The earliest outbreak was in late June in 2014, while the latest outbreak occurred in early August in 2018, 2019, and 2020. The earliest outbreak ended in middle July in 2014, and the latest outbreak ended in late August in 2018, 2020, and 2021.

For the areas prone to cyanobacterial bloom in Hulun Lake from 2013 to 2023, cyanobacterial bloom was more severe on the northwest shore of the lake and less severe on the southeast shore. Among them, the frequency of cyanobacterial bloom was the highest in the southern lake area and the northern coastal area. In 2022, cyanobacterial bloom appeared the most frequently, and the area with cyanobacterial bloom accounted for approximately 68% of the lake surface of Hulun Lake. In 2013, the frequency of cyanobacterial bloom ranked the second, and the proportion of the area with cyanobacterial bloom in the area of Hulun Lake was 59%. In 2021, the lake area with cyanobacterial bloom accounted for more than 41% of the total lake surface area. In 2016, the frequency of cyanobacterial bloom was the lowest in 2016, and the proportion of the area with cyanobacterial bloom in the total lake surface area was about 7%.

2 Meteorological factors affecting cyanobacterial bloom

Cyanobacterial bloom is the result of the combined effect of water environmental factors and meteorological factors^[2]. Based

on the remote sensing and meteorological hydrological data of cyanobacterial bloom in Dianchi Lake, Li Jialong *et al.* analyzed the outbreak characteristics and influencing factors of cyanobacterial bloom in Dianchi Lake, and believed that temperature, solar duration, and wind speed were the main meteorological elements promoting the outbreak of cyanobacterial bloom^[3]. Therefore, based on the data of daily maximum temperature, minimum temperature, average wind speed, and maximum wind speed from the national meteorological observation stations in Manzhouli and New Barag Right Banner in Hulunbuir City from January 1, 2020 to November 14, 2025, the main outbreak periods of cyanobacterial bloom in Hulun Lake from 2020 to 2025 were analyzed based on the conclusion drawn by Lin Cong *et al.*^[4] (the most favorable climatic conditions for the outbreak of cyanobacterial bloom are as follows: daily maximum temperature is 25 – 33 °C, and daily minimum temperature is 10 – 17 °C; daily average wind speed is ≤ 4 m/s, and daily maximum wind speed is ≤ 9 m/s).

2.1 Temperature From 2020 to 2025, the number of days with the daily average maximum temperature of 25 – 33 °C in Manzhouli reached 318 d. Among them, the number of days with the daily average maximum temperature of 25 – 33 °C was the largest in 2024, up to 66 d. It ranked the second in 2020 (56 d) and the third in 2023 (48 d). The number was the smallest in 2022, only 35 d. It was 47 d in 2021 and 44 d in 2025. During a year, daily average maximum temperature was 25 – 33 °C from April to September. From 2020 to 2025, the number was only 2 d in April and 14 d in September. It was the largest in July (reaching 125 d), followed by June (90 d) and August (66 d). In the past six years, the number of days with the daily average minimum temperature of 10 – 17 °C reached 188 d. Among them, the number was the largest in 2024 (up to 41 d), followed by 2021 (32 d), and it was the smallest in 2022 (only 27 d). During a year, there were no days with daily average minimum temperature of 10 – 17 °C, and the number was 2 d in September. July had the largest number (up to 82 d), followed by August (54 d). It was 46 d in June and only 4 d in May.

During 2020 – 2025, the number of days with the daily average maximum temperature of 25 – 33 °C and the number of days with daily average minimum temperature of 10 – 17 °C both reached 399 d. Among them, 2020 had the largest number of such days (up to 73 d each), followed by 2023 (72 d). It was 69 d in 2021, 62 d in 2022 and 2025, and 61 d in 2024. During a year, daily average maximum temperature was 25 – 33 °C, and daily average minimum temperature was 10 – 17 °C from May to September. August had the largest number (up to 134 d), followed by June (110 d) and July (75 d). May had the fewest days, only 27 d. In September, the number was 53 d.

2.2 Wind speed From 2020 to 2025, the total number of days with the 2-minute average wind speed of ≤ 4 m/s in Manzhouli

was 495 d. Among them, 2021 had the largest number of such days (reaching 87 d), followed by 2023 (86 d) and 2024 (85 d). 2020 had the smallest number (only 75 d), and the number was 81 d in 2022 and 2025. The number of days with the 2-minute average wind speed of ≤ 4 m/s from May to September was analyzed, and it was above 100 d from July to September. Among them, August had the largest number (reaching 125 d), followed by July (113 d), September (102 d), and June (94 d). It reduced obviously in May, only 61 d. In the past 6 years, the total number of days with the daily maximum wind speed of ≤ 9 m/s in Manzhouli was 508 d. The maximum appeared in 2021 (up to 98 d), followed by 2023 (90 d), 2022 (83 d), 2024 (85 d), and 2025 (86 d). 2020 had the fewest days, only 66 d. From May to September, the number was the largest in August (reaching 130 d), followed by July (114 d) and September (108 d). May had the fewest days, only 59 d. In June, it was 97 d.

During 2020–2025, the total number of days with the 2-minute average wind speed of ≤ 4 m/s in New Barag Right Banner reached 443 d. Among them, the number of such days was the largest in 2021 (86 d), followed by 2024 (83 d), 2020 and 2025 (72 d). There were fewer days in 2022 (67 d) and 2023 (63 d). From May to September, the number of days with the 2-minute average wind speed of ≤ 4 m/s was above 100 d in July and August. August had the largest number (up to 117 d), followed by July (106 d), September (87 d), and June (84 d). It reduced significantly, only 49 d. In the past six years, the total number of days with the daily maximum wind speed of ≤ 9 m/s in New Barag Right Banner reached 517 d. The maximum appeared in 2024, up to 97 d. The annual average number was 82 d or more in 2020, 2021, 2023, and 2025, of which it was up to 89 d in 2021. It was the smallest in 2022, only 77 d. From May to September, it was the largest in August (reaching 134 d), followed by July (126 d) and September (106 d). The minimum appeared in May (only 63 d), and June had 88 days.

From the above analysis, it can be seen that the number of days with the daily average maximum temperature of 25–33°C and the number of days with the daily average minimum temperature of 10–17°C in Manzhouli were both the largest in July, followed by August and June. Those of New Barag Right Banner were both the largest in August, followed by June. The number of days with the daily average 2-min wind speed of ≤ 4 m/s and the number of days with the daily maximum wind speed of ≤ 9 m/s in both Manzhouli and New Barag Right Banner were both the largest in August, followed by July and September. The favorable meteorological conditions are basically consistent with the analysis results that the cyanobacterial bloom in Hulun Lake occurred mainly from June to September and most frequently from July to August.

3 Measures for the control of cyanobacterial bloom in Hulun Lake

3.1 Strengthening ecological environmental protection With the changes in global climate such as temperature increase and precipitation decrease, the climate is developing towards warming and aridification. Due to the impact of periodic droughts and human activities, the water level of Hulun Lake has continued to drop, and the lake surface has shrunk significantly; wetlands have contracted, and the number of wild animals has decreased sharply. As a result, the resources such as wetlands, sandy land, grassland and forest have changed, thereby posing a serious threat to the ecological security. Therefore, it is necessary to actively respond to the impact of climate change, strengthen the protection of the ecological environment in Hulun Lake, restore wetland ecosystem, ensure water resource supply, and promote the stable development of the ecological environment in Hulun Lake.

3.2 Enhancing the construction of monitoring and early warning capability Hulun Lake is an algal lake. It is difficult to completely control cyanobacterial bloom solely through human efforts. The outbreak of cyanobacterial bloom requires certain environmental conditions. Hence, it is necessary to enhance the monitoring and early warning of the lake, build a complete monitoring and early warning system, increase the construction of monitoring networks in key ecological areas, and utilize comprehensive reliable meteorological and hydrological data as well as the monitoring data of water quality to scientifically carry out protection and governance work. At the same time, it is needed to introduce high-level scientific researchers, rely on in-depth and systematic scientific research, conduct research on causes of water quality and eutrophication based on following natural laws, and adopt artificial intervention measures and precise governance and protection measures.

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