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Formation Mechanisms and Control Methods of Cyanobacteria Bloom

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Abstract. Water, a vital resource of human, has been contaminated to an unprecedented extent worldwide. The formation mechanisms and control methods of cyanobacteria bloom have raised several serious concerns globally due to their significant implications for aquatic life, water environment, and public health. This paper explores causes, forming mechanisms, and control methods of cyanobacteria blooms in the context of biological water pollution. Identifying different types of pollution and forms of pollutant is crucial for determining the most suitable solution. Various factors influence the growth of cyanobacteria blooms, including natural processes and human activities. The formation process requires the convergence of different factors. Scientists implement targeted control methods to thwart the growth of cyanobacteria bloom based on the stage of the growth and environmental conditions. Future research needs to focus on developing new measures to address cyanobacteria blooms and conceptualizing the complex systems professionally. This paper concludes the current findings on cyanobacteria blooms, drawing attention towards further research on cyanobacteria bloom.

Keywords: Cyanobacteria bloom; pollution; eutrophication; temperature.

1. Introduction

Water is vital resource for human survival. However, 2.2 billion people still lack access to safely managed water services, and 115 million people directly drink water from surface water [1]. Water is a crucial link between natural environment and human society. Water pollution is increasingly gaining attention: Different countries are implementing policies addressing these issues. Algal bloom, a typical example of biological pollutant, is a phenomenon of a rapid growth of microscopic algae in water, releasing toxins that threaten aquatic life, water environments, and public health. Among these, cyanobacteria bloom has the widest impact and most severe consequences. Our research goal is to understand principals of the cyanobacteria bloom formation and identify control methods to improve current circumstances. The causes of cyanobacteria bloom vary. There are multiple solutions such as physical, chemical, and biological solutions that suit different scenarios. We aim to combine existing approaches to recognize the most advisable procedures for specific circumstance.

Various research on cyanobacteria bloom covers topics ranging from causes and impacts to managing strategies. Many reviews have developed comprehensive systems to interpret different research in a broader perspective. Though, some generic information also needs improvement to be more systematic. Therefore, this paper recaps evidence and findings about cyanobacteria bloom from latest reviews and research.

The main focus of this paper is to identify the most suitable solution regarding different situations of cyanobacteria bloom. First, the researcher introduces different methods for sorting water pollution, the most direct way to distinguish different scenarios. Next, the researcher analyzes factors influencing the growth rate of cyanobacteria bloom and also the formation of cyanobacteria. Finally, the effective management of cyanobacteria bloom requires the combination between preventive and intervening strategies against growing threat of cyanobacteria bloom.

2. Water Pollution Categories

Recently, approaches to prevent and control water pollution have become a worldwide focus. Numerous scientists and engineers are trying to find out factors for water pollution. A thorough classification system enables smooth communication about basic situation of the water body and pollution and abates misunderstanding. In general, the most common method to classify the type of water pollution is to identify its sources of pollution and nature of pollutants.

2.1. Sources of Pollution

Sources of pollution mean the origins of pollutant. It is generally separated by two categories. They are point sources and non-point sources. The most direct way to separate the two terms is that whether the pollution source is single and identifiable [2].

2.1.1. Point sources

Point source water pollution originates from contaminants entering a water body from a single, identifiable source. The common sources for this might be a factory discharging wastewater from the outfall or a power plant that release heat, acids, or salts into the water body. The Clean Water Act has established policies that require factories, sewage treatment plants, and other point sources to acquire permission to discharge their waste into any water body [3].

2.1.2. Non-point sources

Non-point source (NPS) water pollution usually refers to the form of pollution where the specific source of pollution hasn’t been identified. The precipitation that carries chemical pollutant like nitrogen and phosphorus might be a typical example of NPS pollution. Traditional resolvents like emission taxes or new policies might not be effective for NPS because it is difficult to find all piece of information of the pollutant [4].

2.2. Nature of Pollution

The substance or the form of energy that is able to have negative impact for environment stability or human health is pollutant. There are a lot of forms of pollutants such as physical, chemical, biological, and radiological pollutants. They usually accompany negative effects in terms of color, taste, or odor. While some pollutants like heavy metals, radioactive wastes, or pathogens are impossible to perceive with human senses, they still post serious threat to human body [5].

2.2.1. Physical pollutants

Physical contaminants, including sediments or organic matter that suspend in lake, river, and stream water, primarily affect the physical appearance or water properties. A lot of natural processes such as excessive rainfall, gusty wind, and flow of water can be the factors of erosion by making soil susceptible to be washed, blew, and carried away. Human activities like overgrazing, deforestation, and construction pollution also destroy plants and reduce vegetal cover, so that the soil is exposed to natural forces exerted by rainfall, gusty winds, and flow of water, accelerating soil erosion.

2.2.2. Chemical pollutants

Chemical contaminants, consisted of chemical elements and components, are usually byproduct of manufacturing processes and other human activities that involve large amount of harmful chemical waste through the incomplete chemical reactions. Represented by nitrogen, bleach, and metals, chemical pollutants affect balance in the ecosystem. For example, due to their large density, heavy metals will soon settle in sediment after entering water. The disturbance might make these heavy metals reenter the water column, posing a long-lasting threat to aquatic animals and ecosystem. More severely, they might enter the food chain after they are eaten and digested by one of the aquatic animals in accident. In this way, chemical pollution poses a substantial environmental impact on both ecosystem and humans. Tackling chemical pollutants, especially organic substance, involves great challenges. Pollutants with wide ranges of physical and chemical properties are difficult to identify.

Moreover, transformative reactions of chemical pollutants are often accompanied by various biological processes, complicating analysis of environment conditions. Most of the time, scientists can only identify the category of the water pollution, but they cannot recognize the type of the chemical, which leads rooms for progress of further exploration [6].

2.2.3. Biological pollutant

Biological contaminants are organisms in water, including bacteria, viruses, fungi, worms, and algae, posing serious threat to ecosystem and human beings. They usually come from human waste like inadequate sewage discharge of pathogens from feces, animal waste like bacteria from wildlife washing, and industrial processes like organic matter from manufacturing processes. The principals for biological pollutant are hard to interpret because these small creatures are usually accompanied by other substances and other types of pollutant [6]. Excessive number of these biological contaminants not only simulate allergic reactions for human body, some of the microbes might also lead to serious diseases like water-borne diseases. Harmful algae can produce toxins that kill other aquatic organisms and deplete oxygen.

2.2.4. Radiological pollutant

Those substances that emit ionizing radiation in surface water or ground water are radiological pollutant. As the increment of the radioactive pollution case has been discovered by human, we gradually realized that radioactive pollution has become one of the most threatening class of pollutants in water body. Radiological pollutants are usually in the form of radioactive isotypes. These pollutants can usually be provided by natural processes and human activities. Some radioactive isotopes have very long half-lives, and they have existed since the formation of the Earth, while some other radiogenic radioisotopes are produced by the decay of radioactive isotopes. With the wide involvement of the usage of radioactive materials, radiological pollutant is inevitably disposed to the aquatic environment in the form of waste materials [7]. Nuclear reactions in reactors, medical and industrial application, and other human activities can all produce radioactive isotopes like Cobalt-60, Iodine-131 and Iridium-192. Improper disposal of these isotopes will pose serious threat to public health and the environment. For example, if farmers use contaminated water for irrigation, the crop we consumed will encompass radioactive isotopes.

3. Cause and Mechanism of Cyanobakteria Bloom

3.1. Cyanobacteria

Cyanobacteria, known as blue-green algae, is one of the oldest prokaryotes on the Earth. Paleontological, geological, and isotopic geochemical evidence has indicated that cyanobacteria already existed 3500 Ma ago in stromatolitic microbial ecosystems. They usually accumulate, float, and bloom in the eutrophic lakes, reservoirs, rivers, and other water bodies. Their metabolic versatility enables them to photosynthesize and respire within the same cell at the same time. Their longevity and dual metabolic capacity cultivate a sophisticated adaptation system. In this way, Cyanobacteria can reproduce and bloom very quickly once given a suitable condition. Cyanobacteria get their name form their physical appearance of blue green color. Sometimes, you can also see white, brown, or red bloom. They also have distinct smells: They are usually very grassy or septic, and sometimes people might feel nauseous when they smell it. Like other harmful algae, cyanobacteria release stink and toxic substances to deteriorate situations of water. Of all algae blooms, cyanobacteria bloom gains the widest range of implications and harm towards the human health and environmental system. Recently, the frequency of cyanobacteria bloom occurrence keeps increasing, especially in regions near lakes [8]. Global distribution of lake bloom intensity trends shows that the peak summer time bloom intensity has increased since the 1980s [9].

3.2. Cause

Nowadays, the occurrence of cyanobacteria bloom has become more frequent as eutrophication recurs. A lot of regions around the world have been influenced by cyanobacteria bloom by varying degrees. For example, over 70% of lakes across China are affected by eutrophication due to urbanization and overfarming. The number might display an increasing inclination without proper intervention measure, leading to an adverse impact on water quality and biodiversity. Another example is that approximately 15000 water bodies are influenced by eutrophication due to the excessive agricultural activities according to EPA reports. These current situations of eutrophication might keep on deteriorating without proper intervening measures. Generally, the factors that why cyanobacteria bloom is produced are attributed into three factors: suitable temperature and lighting, excessive nutrition, and still water.

3.2.1. Light

The radiation of the light influences the rate of the respiration of the cyanobacteria [10]. As the condition of the photosynthesis, lighting plays an important role in providing energy for cyanobacteria’s metabolism. Either in stratified conditions or the mixed conditions, cyanobacteria have demonstrated its good adaptabilities when they gain lights with the help of phycobilin pigment. This allows them to utilize only a little energy to maintain their life. Light has direct relation with the formation of cyanobacteria. Taking advantage of this principal, some scientists are trying to use the growth of plankton to identify the lighting intensity. It is usually considered that eutrophication is the main factor of the cyanobacteria bloom. However, research has shown that light intensity, rather than eutrophication alone can be the prior regulator of a lake. Light has been proven to play a significant role in controlling the overall biological balance in an ecosystem. For Lake Okeechobee, underwater light availability, including resuspended sediments and water column stability influences the lake is dominated by low light adapted, non-bloom forming taxa or high light adapted, bloom-forming taxa [7].

3.2.2. Temperature

Photosynthesis plays a significant role in providing cyanobacteria with energy for growth and maintenance. As the main contributor to the Earth’s oxygen, cyanobacteria’s photosynthetic capacity is instrumental. Research shows that the growth of cyanobacteria is heavily dependent on temperature. Metabolic processes, photosynthesis efficiency, and membrane fluidity are all dependent on the temperature [11]. Enzymes drive metabolic reactions within a specific temperature range. Similarly, photosynthetic efficiency decreases in colder temperature due to reduced electron transport and ATP production. Membrane fluidity, crucial for nutrient transport and cellular integrity, is also temperature sensitive. Low temperature will make membranes too rigid, disrupting cellular processes. In other words, high temperature will promote cyanobacteria growth. Other algae are influenced by the warmer conditions, giving cyanobacteria an edge. On the contrary, a lot of cyanobacteria even cannot bear the cold environment. For instance, the growth rate and the photosynthesis efficiency of Synechocystis, a cold-sensitive cyanobacteria, significantly decrease below 22° Celsius. On the other hand, Microcystis, a single-celled freshwater cyanobacteria, has a wider range of living temperatures although it struggles to maintain its optimal cellular functions below 15 ° Celsius. Although nutrient richness and hydrology are more influential than temperature on photosynthesis and reparation rate, exposing themselves to sunlit remains crucial for cyanobacteria survival.

Climate change has provided them with warm water, an ideal environment for cyanobacteria to grow and reproduce fast. Earth's temperature has risen by an average of 0.11° Fahrenheit (0.06° Celsius) per decade since 1850 [9]. The warmer climate offers cyanobacteria a great opportunity to dominate the entire water body, often outcompeting other algae especially in the stable summer water, leading to more frequent and severe blooms.

3.2.3. Nutrition

Nutrition is base for cyanobacteria growth. Abundance of nutrition largely influences the photosynthesis and metabolism rate of cyanobacteria. When the nutrition levels are high, cyanobacteria bloom usually occurs frequently. Nitrogen and phosphorus are two main elements associated directly with cyanobacteria. Nitrogen is the fundamental component of amino acid, forming blocks of protein necessary for basic structures and functions of cyanobacteria. It is also essential for synthesizing chlorophyll, capturing light energy during photosynthesis. Phosphorus is also the raw material of the DNA and RNA, playing an important role in genetic storage and information transformation. Phosphorus is also crucial for ATP production, the energy currency of cells and the pathway to transfer energy within cells. Hence, the concentration of the nitrogen and phosphorus in water is positively correlated with cyanobacteria growth. Agricultural runoff and wastewater discharge, including human waste, food, and detergent, often release these nutrients into water bodies.

Climate change affect the proportion of the nutrition. Increased precipitation driven by climate change wash more nutrition into lakes, expanding cyanobacteria-dominated area. Moreover, wild wind stirs up sediments under the lake, sot that these sediments suspend again. Basins near lakes bring nutrition to the lake, contributing to cyanobacteria growth.

3.2.4. Water conservancy project

Water conservancy projects, especially damming, significantly influence cyanobacteria growth. Depending on types of dams, these projects have either have positive or negative impacts. Many dams have reservoirs for the multiple functions such as water supply, flood control, and irritation. Most of the reservoirs are very shallow, providing suitable conditions for cyanobacteria to reproduce and bloom. Additionally, by reducing the natural flow of rivers, dams also provide cyanobacteria stagnant water, a perfect habitat for cyanobacteria.

Stagnant water usually has higher nutrient concentration, serving as reliable food sources for cyanobacteria. Moreover, cyanobacteria can take advantage of the light availability there due to less suspended particles and sediments blocking sunlit. Stagnant water can easily form thermal stratification. raising surface temperatures. Reduced mixing lead to oxygen depletion in the water, giving cyanobacteria an edge to perform better in oxygen-lacking environments.

Conversely, some water conservancy projects may negatively impact cyanobacterial growth. Projects that increase water flow during certain period reduce stagnation and hence prohibit bloom. Moreover, it disperses cyanobacteria and dilute the concentration of the nutrition. Some projects establish vegetated buffer zones along the upstream to prohibit nutrition from reaching downstream water bodies.

Overall, the formation of cyanobacteria blooms is caused by different complicated factors, usually integrated nature with human factors. Fig. 1 is the diagram of factors affecting cyanobacteria blooms.

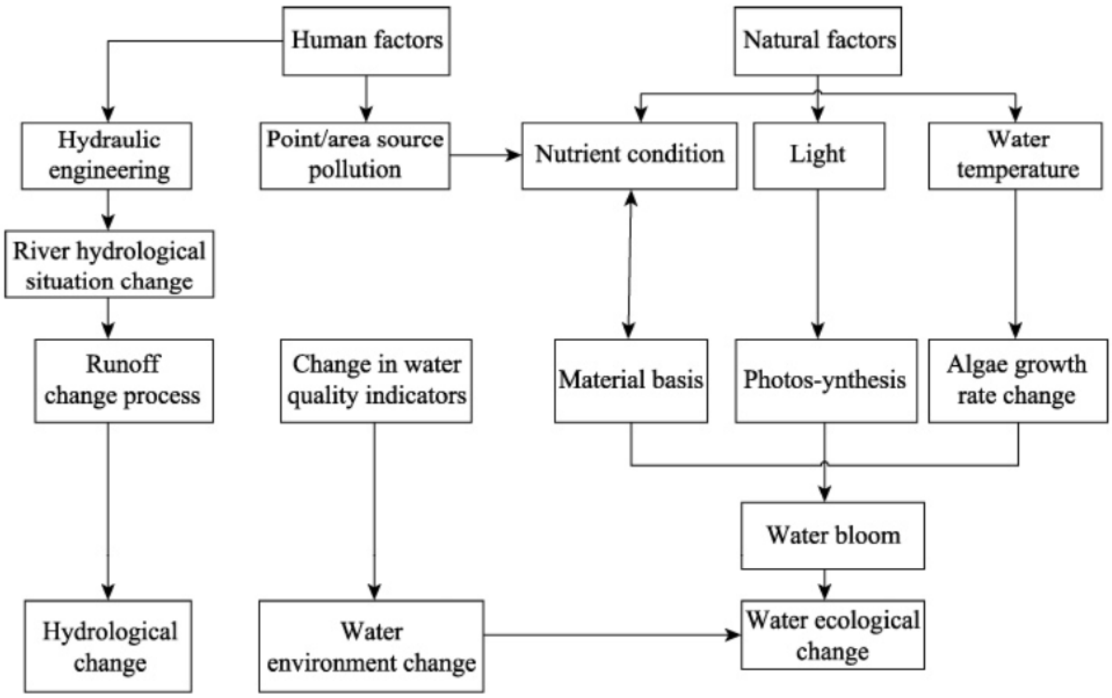

Fig 1. Diagram of factors affecting cyanobacteria blooms [12]

3.3. Forming Mechanism

Firstly, nutrients, especially nitrogen and phosphorus, enter habitats of cyanobacteria through agricultural runoff or wastewater discharges. Sometimes water flow or extreme weather might release nutrients from the sediments under the water. A few cyanobacteria start to utilize such little nutrients for growth and reproduction. Cyanobacteria uses sunlight to convert carbon dioxide and water into oxygen and organic matter, increasing their biomass. Given warm temperatures and stable conditions, the water body becomes stratified, forming distinct layers with warmer, nutrient-rich water at the surface. Appropriate conditions like temperature, sunlight, and nutrient concentration foster rapid population growth. Gas vesicles help cyanobacteria gain buoyancy, enabling them to stay at the surface where optimal light and nutrients are available. As cyanobacteria pollution grows, a bloom forms on water surface, usually appearing green, red, or blue. Some cyanobacteria species release toxins that can be harmful to aquatic life and humans. In some cases, cyanobacteria form mats that either float on the surface or sink to the bottom. As the bloom thrives, it eventually depletes all available nutrients in the water. The bloom starts to decay, and the decomposition process requires more oxygen than cyanobacteria need for growth, leading to hypoxic conditions that harm other aquatic organisms and environment again. The released nutrients released after decomposition can be used by other aquatic organisms or remaining cyanobacteria. A new cycle of competition begins.

4. Control Measures of Cyanobacteria Monitor

4.1. Preventive Measures

Cyanobacteria release toxins into the water, causing diseases and the death of plants, animals, and even human. This adverse impact deteriorates ecological balance and poses significant risks to human health. Consequently, scientists continually seek ways to prevent cyanobacteria blooms. Governments impose policies to regulate wastewater emissions and fertilizer usage, preventing excess nutrients from entering water bodies. Land use practice, such as preventing overgrazing and deforestation, promote sustainable agriculture and control erosion near water bodies to reduce nutrients runoff. Moreover, different countries should reduce greenhouse gas emissions and prevent climate change, decreasing the conditions that benefit cyanobacteria.

4.2. Interventive Measures

If a cyanobacteria bloom has happened, interventive measures should implemented to ensure the situation will not expand. Physical, chemical, and biological measures are all applicable for remedying blooms. Aeration, the physical measure, increases dissolved oxygen and dsirupts stable conditions for bloom formation. Barley straw can act as chemical measures to release algicides gradually to kill cyanobacteria. Humans can also introduce predators of cyanobacteria like Candidatus Cyanoraptor togatus or foster the growth of competing in the same ecological niche.

5. Conclusion

Cyanobacteria blooms pose serious threat to aquatic life, water environments, and public health. This paper discusses different categorization methods to identify specific polluted circumstances of cyanobacteria bloom, indicating that both point source (like industrial discharge) and non-point source (like agricultural runoff) can contribute to the water pollution. Pollutants can be categorized as physical, chemical, biological, and radiological. Understanding these pollutants specially can help in utilizing targeted measures. Light, temperature, nutrition, and water conservancy project are all factors that more or less contribute to the rapid growth of cyanobacteria bloom. While these factors collectively stimulate blooms, in specific cases, excess amount of one particular factor can directly generate a disaster. The implication of cyanobacteria bloom cannot be underestimated. Preventive measures have already been implemented to mitigate outbreaks. Depending on specific cases, physical, chemical, and biological measures have their advantages. Preventing bloom and controlling their scale are two key goals of cyanobacteria bloom research. Developing more comprehensive systems to identify the best solutions for different scenarios is crucial. Governments also need to enforce policies to regulate emission and waster while ensuring the stable economic. The paper concludes recent studies about the forming mechanism, causes, and control methods of cyanobacteria bloom.

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