Innovative restoration for eutrophic drinking water sources: approaches, application and evaluation

Chen Lan[1]

[1]Guizhou University of Finance and Economics

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Abstract

Drinking water sources have higher water quality requirements because of their special uses. Many drinking water sources in the world have been polluted or are being polluted for a long time, resulting in eutrophication. We define the approaches that have been developed in the last 10 years and achieved good effect as innovative restoration approaches. In this paper, the traditional, and frequently used restoration approaches in recent 30 years were briefly reviewed, and the innovative technologies and methods were summarized and evaluated in detail. In light of the impact of COVID-19, we have also put forward rational suggestions on water quality restoration of transboundary rivers to provide scientific reference for global public health safety and protection.

Innovative restoration for eutrophic drinking water sources: approaches, application and evaluation

Chen Lan *

School of Management Science and Engineering, Guizhou University of Finance and Economics, Guiyang 550025, China;

*Correspondence: lanchen@mail.gufe.edu.cn (C.L.)

Abstract: Drinking water sources have higher water quality requirements because of their special uses. Many drinking water sources in the world have been polluted or are being polluted for a long time, resulting in eutrophication. We define the approaches that have been developed in the last 10 years and achieved good effect as innovative restoration approaches. In this paper, the traditional, and frequently used restoration approaches in recent 30 years were briefly reviewed, and the innovative technologies and methods were summarized and evaluated in detail. In light of the impact of COVID-19, we have also put forward rational suggestions on water quality restoration of transboundary rivers to provide scientific reference for global public health safety and protection.

Keywords: eutrophication, drinking water sources, COVID-19, transboundary water, public health

1. Introduction

Drinking water sources refers to the water area and the related land area with a certain water supply scale, including rivers, lakes and reservoirs, which can provide water for urban residents and public services. Surface water and groundwater are usually regarded as the raw water supply sources for drinking water (Katsanou & Karapanagioti 2017). According to the different geographical and hydrological conditions, different countries or regions will decide to obtain water resources from different raw water supply sources (Stuyfzand & Raat 2010; Gaget *et al.* 2017; Gao *et al.* 2018; Bexfield*et al.* 2019; Carrard *et al.* 2019; Li *et al.* 2019). Considering development difficulty, technical difficulty and investment cost, the surface water sources, include rivers, lakes and reservoirs, which can be found in many places of the earth, was chosen for development and utilization of water resources in lots of regions (Tang*et al.* 2014; Skariyachan *et al.* 2015; Duan *et al.*2017; Li *et al.* 2018). However, many of these water sources around the world are eutrophic due to ongoing damage or serious pollution in the past (Mehner *et al.* 2008; Conley *et al.*2009). Eutrophication will lead to significant deterioration of water quality, and the content of toxic gas of hydrogen sulfide and harmful heavy metals exceeds the standard (Chen *et al.* 2015; Huser*et al.* 2016; Sinha *et al.* 2017; Sojka *et al.* 2018). Moreover, a large number of reducing compounds appears due to the water hypoxia caused by eutrophication, with the combined effects of hydrogen sulfide, will cause color, smell and taste problems in water quality, which increasing the cost of water treatment (Bierlein *et al.*2017; Geerdink *et al.* 2017; Vinçon-Leite & Casenave 2019). The removal of reducing compounds will also increase the dosage of oxidants in drinking water treatment equipment, such as liquid chlorine. Excessive oxidant consumption can form disinfection by-products, causing secondary pollution and affecting human health (Zhai *et al.*2017). The restoration of eutrophic drinking water sources is urgent extremely. So far, a variety of restoration approaches targeting drinking water sources were developed, presenting varying implement difficulty and restoration effectiveness (Erftemeijer & Lewis III 2006; Vickie & John 2006; Bormans *et al.* 2016; Sillanpaa *et al.*2018; Preece *et al.* 2019; Parde *et al.* 2021). In terms of time, comparing to the approaches that have been existed for more than half a century approximately, some approaches are relatively new and have only been developed and applied in recent decades.

The aims and significance of this review were as follows: (1) to distinguish old approaches from new approaches better and lay a good foundation for the improvement or optimization of approaches subsequently; (2) to understand the dynamics information of lake restoration; (3) to minimize the time spent researching lake restoration techniques or methods; and (4) to avoid repetitive work and improve the significance and value of research. This paper made a brief review of the traditional and frequently used restoration approaches, summarizing the innovative technologies and methods of drinking water source restoration in detail, and giving a more focused evaluation on the innovative restoration.

2. Materials and Methods

Based on the investigation of the published literatures in the past, we obtain the information about this study to analyze and comb the research content of innovation restoration comprehensively. The research in this paper was carried out based on Web of Science and Google Scholar. All databases included in these two retrieval platforms are searched. We conducted a comprehensive literatures search on these two platforms and found almost all literatures about the restoration approaches of eutrophic drinking water sources. Of course, the literatures we search and filter must be published in English. These related papers are classified as the screening papers of this study. All relevant literatures were screened and selected by the authors independently to assess their relevance to the purpose of the review. A large number of articles found in the search progress were filtered to exclude the literatures which were not suitable for the purpose of the review. Among the selected qualified papers, we summarized the traditional and innovative restoration techniques or methods. We defined innovative restoration approaches as those which do not belong to traditional restoration approaches, and have appeared in the recent 10 years.

3. Results and Discussion

3.1 Traditional approaches with high application frequency

Traditional approaches are a kind of pollution control techniques or methods for direct treatment of sediment pollution sources. A large number of studies have shown that after controlling the input of exogenous phosphorus effectively, the release of endogenous phosphorus can still maintain the eutrophication state of water body for a long time, and even directly lead to sudden water quality deterioration events such as blue algae outbreak (Heisler *et al.* 2008; Watson*et al.* 2016). When the exogenous input was gradually controlled, the release of endogenous phosphorus accelerated the eutrophication process of the lake (Wang *et al.* 2019; Zhan *et al.* 2019). How to effectively control endogenous pollution of sediment is the key to eutrophication management. According to the different principles, traditional restoration can be divided into physical restoration, biological restoration and physicochemical restoration. Among the three categories, the most frequently used technologies include sediment removal, reoxygenation, hypolimnetic withdrawal, phytoremediation and in situ passivation.

3.1.1 Physical restoration

Sediment removal mainly uses engineering measures to eliminate sediment pollution. This method can directly remove the polluted sediment out of the system. The typical engineering technology adopted is environmental dredging. Environmental dredging is the interdisciplinary engineering technology of dredging engineering and environmental engineering which originating from Japan and western (Pequegnat 1975; Terashima *et al.* 1991). In 1969, the first lake dredging project aimed at improving the water environment was carried out in lake Suwa in Japan (K *et al.* 1995). So far, many lakes or reservoirs in the world have been carried out the dredging restoration (Erftemeijer & Lewis III 2006; Patmont & Palermo 2007; Bridges *et al.* 2010; Fox & Trefry 2018; Chen *et al.* 2020a).

Reoxygenation technology began with the reoxygenation system developed by Mercier et al. in 1949 (Mercier & Perret 1949). Its principle is to complete the water reoxygenation of lake by pumping the hypoxic water from the lake bottom to the lake surface. In 1973, Fast et al. used the side flow pump to pump the hypoxic water in deep water to the oxygen output pipe on the shore for reoxygenation, which was one of the earliest reported application cases of hypolimnetic oxygenation engineering in the world (Fast *et al.* 1975). In the following years, experts continued to study the technology of hypolimnion reoxygenation and optimize the reoxygenation method (Speece *et al.* 1971; Whipple *et al.* 1975). Up to now, reoxygenation has been successfully used to restore water environment in many lakes in the world (Vickie & John 2006; Choi & Ahn 2014; Lan *et al.* 2017; Preece *et al.* 2019; Lan *et al.* 2021).

Hypolimnetic withdrawal is a technique for extracting rich nutrients and reducing substances from the water body in lower lake during the stratified period of eutrophic lakes to reduce the load inside the lake (Bormans *et al.* 2016). It has been more than 60 years since the method was first used (Dunalska *et al.* 2007). Hypolimnetic withdrawal could be useful in improving water quality (Nürnberg 1987, 2007; Dunalska *et al.* 2014). Moreover, it is most useful for stratified lakes with high nutrient content in the hypolimnion (Nürnberg 2019).

3.1.2 Biological restoration

Phytoremediation method is to use large submerged plants to degrade sediment pollutants and eliminate or reduce the toxicity of pollutants (Melzer 1999; Park *et al.* 2016). Transplanting submerged plants can absorb nitrogen and phosphorus from sediment into the plants and reduce the release flux of phosphorus at sediment-water interface. In recent decades, there have been many cases of using phytoremediation to restore water environment of lakes (Knopik & Newman 2018; Wang *et al.* 2020c; Li *et al.* 2021).

3.1.3 Physicochemical restoration

The principle of in situ passivation technology is to use chemical reagents and physical covering to fix the pollutants in the sediment in situ. The pollutants in the sediment will be adsorbed, passivated or even prevented from being released into the overlying water. This physicochemical technology has been applied to endogenous remediation of sediment abroad since 1970s (Cooke & Kennedy 1978). In situ passivation has been successfully applied in many lakes abroad, and has attracted more and more attention now (Rydin & Welch 1998; Malecki-Brown *et al.* 2009; Yang *et al.* 2020b).

3.2 Innovative restoration techniques or methods

The approaches that have been developed in the last 10 years, and achieved good effect are defined as innovative restoration approaches. A summary of studies involving the innovative restoration for eutrophic water is present in Table 1.

3.2.1 Comprehensive approach

This comprehensive approach is achieved by a combination of biological, chemical and technical methods(Grochowska 2020). The approach is performed in five main steps based on the current status of the lake: (1) Firstly, the introduced water is purified by hydrophilic plants (*Glyceria maxima, Phalaris arundinacea and Phragmites australis*) and sorption material (expanded clay) for deeply treatment. (2) The second step, as the most important step, is that according to the current load of the lake, the polluted water flowing into the lake must be piped into the bottom to ensure that there is no external negative interference to maintain good water quality; (3) Then, in the phosphorus inactivation method, mainly iron and aluminum coagulants are used to permanently lock phosphorus in the sediment; (4) After a long period of passivation, anti-cyanobacterial preparation will be introduced into the bottom zone. Following the previous step; (5) microbiological probiotic preparation will be added to the same zone to enhance the effect. The earliest successful case of this approach appeared in Poland (Lake Miłkowskie) in 2018 (Grochowska 2020). In this case, the restoration reduced the excess nutrients in the lake and controlled the growth of phytoplankton.

3.2.2 Combined biomanipulation (CB)

The concept of traditional biomanipulation was first proposed in 1975 (Shapiro 1975). Biomanipulation refers to the management of aquatic communities that control natural populations of organisms for the purpose of improving water quality (Kasprzak *et al.* 2002; Mehner*et al.* 2002; Jeppesen *et al.* 2007). CB accomplished by combining 4 methods, including creating submerged plant, fish, macrobenthos, and zooplankton communities. Prior to this combined approach, most of the biomanipulations (such as fish biomanipulation, zooplankton biomanipulation, planting of submerged macrophytes, constructing ecological floating beds and effective microorganisms) were often applied independently to the specific water bodies in which they were good at purifying (Zeng *et al.* 2017; Liu *et al.* 2018; Bi *et al.* 2019). In the case of lakes with complex pollution situation, an independent method or a combination of fewer methods is often difficult to achieve the expected restoration goals. In this context, a combination of four biomanipulations were proposed. In 2018, CB was carried out in lake Dongpo in China. The results show that the implementation effect is good. The transparency of water has been improved, while the contents of total phosphorus, total nitrogen and chlorophyll-a have been reduced.

3.2.3 Ecohydrological restoration approach

The urban rivers, artificial lakes and watercourses, which often been regarded and used as landscape, are a kind of small ecosystems. They are usually formed naturally or constructed artificially, which can give people a sense of beauty. This type of water body is mainly shallow water systems (there are also exist deep water systems in the karst areas (Lan *et al.* 2021)). The ecohydrological restoration approach improves inflowing water by constructing hybrid systems and sequential sedimentation-biofiltration systems (SSBS). Simultaneously, a variety of biological methods including the development of landform-adjusted shoreline vegetation, the construction of floating islands and the regulation of the biological structure of the ecosystem were used to improve water quality and maintain the effectiveness (Jurczak *et al.* 2019a). The results showed that most of the water quality indexes were improved. The nutrient concentration was still lower than before. Moreover, the control of microcystins and chlorophyll-a was also improved.

3.2.4 Geoengineering approach

Oxygen nanobubbles is a kind of water quality restoration approach with high stability and mass transfer efficiency. The principle is that the porous natural mineral zeolite is used to prepare oxygen-carrying materials, which adsorb oxygen based on the huge specific surface area and rich internal pore cavity of the oxygen-carrying materials, and transport the zeolite to the sediment surface by natural sedimentation to achieve efficient oxygen-increasing of sediment-water interface. This method has been widely used in groundwater remediation, surface water remediation and refractory wastewater treatment (Khuntia *et al.*2012; Li *et al.* 2014; Temesgen *et al.* 2017). It has been applied to long-term anaerobic remediation of lake sediment-water interface in recent years (Shi *et al.* 2018; Zhang *et al.*2018; Yu *et al.* 2019; Wang *et al.* 2020a; Zhang *et al.* 2020).

3.2.5 Green energy artificial floating island (GAFI)

Artificial floating island (AFI) are variations of wetlands, aquatic or terrestrial plants, growing in a hydroponic manner with buoyant frames floating on the surface of water bodies (Chang *et al.* 2017).

AFI are divided into three categories, including traditional plant floating island technology, complex floating island technology and moveable floating island-wetland technology. The three artificial floating island technologies are gradually upgraded and perfected in terms of technical complexity and application scope. Traditional plant floating island technology consists of polymer material carrier and aquatic plants. Based on the former, complex floating island technology replaces polymer material carrier with more advanced fixed biofilms or biocords. Moveable floating island-wetland technology makes AFI movable and adding wetland to improve water quality (Chang *et al.* 2017). GAFI was combined the advantageous components for AFI with an aerator device powered by a solar system. In 2012, this technology was implemented in the lake Lize, China, for the first time and achieved good restoration effect (Lu *et al.* 2015). Compared with the traditional artificial floating island technology, it can quickly improve the water quality in a short period of time and reduce the nitrogen content of the water body. Subsequently, some cases about the application of this technology were published (Chang *et al.*2014a; Chang *et al.* 2014b; Chang *et al.* 2014c; Chen*et al.* 2014; Yeh *et al.* 2015).

3.2.6 Improved effective microorganism (IEM)

Microbial biotechnology is the most recent approach to waste water treatment (Mielczarek *et al.* 2013). Effective microorganism (EM) method is one of the restoration methods proposed in recent years. It was primarily proposed by Dr. Teruo Higa in Japan (Higa & Parr 1994). The microorganisms of EM aiming at the inhibition of harmful bacteria through competitive exclusion (Dondajewska *et al.* 2019b). In recent decades, many cases of EM implementation have been reported (Szymanski & Patterson 2003; Zakaria *et al.* 2010; Shalaby 2011; Sitarek *et al.* 2017). In 2015, an method was named as IEM was developed to restore water quality in a wetland in Republic of Korea (Park *et al.* 2016). The principle of the improved method is to mix 450 g loess, 25 mL of EM solution, 25 g EM bokashi mixture to produce EM soil balls in weight of 500 g. After soil balls producing, they were incubated for 6 days for microbial growth. In order to improving the hardness of the soil balls carrier, calcium oxide, silicon dioxide and citrate buffer (for pH controlling) were added in a certain proportion to the soil ball-making process. The result of the case showed that the modified soil balls effectively improved the water quality of the ponds, the lakes, and the streams.

3.2.7 Sustainable approach

Sustainable approach is a restoration approach based on the concept of nature-based. The implementation effect of traditional restoration methods is temporary or expensive. This approach is a new method to restore the polluted water quality of lake by using the internal restoration mechanism of the ecosystem itself. The application of this approach can gradually restore or reconstruct the ecosystem without intense and expensive human intervention. The sustainable approach was implemented in lake Uzarzewskie, Poland in 2008. In this case, a combination of physical, chemical and biological methods was used to improve the water quality.

The physical method mainly uses hypolimnion aeration, the chemical method mainly uses compounds with phosphorus prediction, and the biological method mainly uses biomanipulation which based on fry stocking. In addition, the water with high nitrate concentration is introduced to the bottom of the anoxic lake. After 10 years of continuous monitoring, the results showed that the total biomass decreased, as well as chlorophyll-a. The water transparency increased significantly to an average of 2 m. Cyanobacteria were replaced by *diatoms* , *dinoflagellates* and *chrysophytes* .

3.2.8 Large-scale constructed wetland (LCW)

Constructed wetland (CW) is a comprehensive ecosystem constructed and controlled by man-made operation. It uses the triple synergy of physics and biology to purify the polluted water body. CW has been widely used to treat various types of wastewater for a long time, such as textile waste, dairy waste, industrial waste, piggery waste, tannery waste, petrochemical waste, municipal waste, etc (Calheiros *et al.* 2007; Saeed *et al.*

2019; Parde *et al.* 2021). It was also reported that CW are used in flood control, habitat for wildlife and recreational space (Brouwer & Bateman 2005; Janssen *et al.* 2005; Davis *et al.* 2008). Some studies in recent years have shown that LCW can also be used to improve lake water quality of eutrophication (Dunne *et al.* 2012; Dunne *et al.* 2013; Martín *et al.* 2013). However, judging from the results of our investigation, there are not many published cases. In 2003, the earliest case of LCW used to treat the water quality of eutrophic lake appeared in the lake Apopka, USA (Dunne *et al.* 2012). Waterflows passed through the marsh flow-way by gravity in this system of the case, entered each of the four independently operated cells via gated culverts, and was purified finally.

3.3 Evaluation of the innovative restoration techniques

In this section, we first classify the above eight innovative technologies into combined implementation type and independent implementation type according to the principles. The classification standard here is mainly based on whether the principle of this approach involves three or more of the physical, chemical, biological, physicochemical, biochemical, eco-hydrological, etc. The principle covered one or at most two categories that we define them as independent implementation type, otherwise as combined implementation type. Then, every innovation approach in each category is evaluated in Table 2.

3.3.1 Combined implementation type

Comprehensive approach, ecohydrological restoration approach, CB and sustainable approach are defined as combined implementation type. In the application process of comprehensive approach and sustainable approach, a special kind of technical method is applied, that is, water body is introduced to the bottom of lake through artificial pipelines. The purpose of the same step in the two approaches is similar. The water brought to the bottom of the lake has been purified by plants and reduced nutrients within the comprehensive approach. It contains a lot of oxygen and comes from the sewage treatment plant. The water do not directly discharged to the water surface, which is conducive to control the growth of blue algae and the oxygen supplement in bottom water body. The oxygen-rich water replenishment to the hypolimnion, the oxygen concentration in the lower layer of the lake increases (wind aeration is also for this purpose), which inhibits the release of ammonium nitrogen in the sediments and increases the content of nitrate in the sediments. At the same time, the content of ammonium nitrogen in water was reduced by nitrification. Within the sustainable approach, the spring water with high concentration of nitrate was introduced to the bottom of the hypoxic lake. Its purpose is also to increase the content of nitrate and the redox potential at the sediment-water interface, promote denitrification, and generate molecular nitrogen to be discharged out of the system. Mineralizing bacteria was used mainly because of the higher oxygen content in sediment in the coastal zone of the Miłkowskie Lake, to accelerate the process of mineralization accumulated at the bottom of organic matter. This method is mainly applicable to lakes with high oxygen content in sediment. The removal of phosphorus in these two approaches is precipitation or passivation, which is the conventional phosphorus removal method. The two approaches are suitable for lakes with high level of eutrophication, or the lake need to gradual reconstruct the structure and functioning of the ecosystem without taking too deeply intervening actions (Dondajewska *et al.* 2019a; Grochowska 2020).

Planting aquatic plants has been used to improve water quality within CB and ecohydrological restoration approach, is the traditional method of biological manipulation.

Considering different water quality with water environment conditions comprehensively, to further select other collocation methods. CB is mainly suitable for the shallow lakes which has a high concentration of nutrients even after serious reductions in the load of nutrients, and high concentrations of algae, in particular cyanophytes. The approach has a higher efficiency and a significant effect on water quality that is difficult to treat, involving many principles. Thus, the ecological risk of this approach is very low. It is very friendly to the large lakes of drinking water sources. Ecohydrological restoration approach is mainly applicable to shallow rivers and lakes. The sedimentation system and filtration system in this method are used in conjunction with plant-based biological manipulation. The approach is suitable for urban eutrophication cascade reservoir and small urban water ecosystem. Based on the characteristics of small cascade reservoirs, this technique is very suitable for step-by-step restoration. Some of the urban's rivers with the characteristic of narrow and long, which serve as drinking water sources, also meet the requirements of step-by-step restoration. River landscape is an important urban infrastructure, which not only plays a role in flood control, drainage, shipping, but also undertakes urban tourism, leisure, beautification and other functions. Therefore, planting plants can also beautify the three-dimensional landscape of the city to a certain extent. Aquatic plants provide fish not only with food but also with a habitat to live. At the same time, it can also play a role in purifying water quality through ecological circulation. Planting aquatic plants with different morphological characteristics and flowering period in water meets the requirements of human for water landscape culture.

3.3.2 Independent implementation type

Geoengineering approach, IEM, GAFI and LCW are defined as independent implementation type.

Oxygen nanobubbles is a new method to restore eutrophic lakes by increasing oxygen and reducing the content of phosphorus and other nutrients in water. The most important advantage of oxygen nanobubbles method is that it can directly oxygenate the sediment water interface. The traditional oxygenation principle mainly includes two categories which is breaking the thermocline, mixing the upper and lower water bodies, and injecting air or oxygen into the hypolimnetic water bodies of the lake. The former carries out oxygen mass transfer through the exchange of oxygen-enriched water on the water surface and anoxic water on the bottom of the lake, having a lower reoxygenation efficiency. Injecting air or oxygen into the hypolimnion is an improved reoxygenation method based on the former. The efficiency has been greatly improved. Although the traditional reoxygenation methods having high efficiency, no matter what kind of traditional reoxygenation principle is selected, large engineering equipment or cost will be used, which is very difficult for institutions with limited funds or inconvenient field operation. Compared with other oxygenation methods, oxygen nanobubbles method only needs to put the configured oxygen-carrying materials into the water body directly from the water surface, and sinking by gravity to the sediment-water interface. This method not only greatly speeds up the contact time between oxygen and sediment water interface, but also is very cheap from the perspective of cost. Effective microorganism is a new compound microbial agent, which does not contain harmful substances and does not pollute the environment, and can be used to degrade nitrogen and phosphorus in water. In many cases with mass flow and high flow rate (especially in some rivers and streams), the structure of the soil balls was not stable enough to be dispersed. By proportionally adding calcium oxide and silicon dioxide during the producing process increased hardness of the soil balls for four times. This is more conducive to the stable existence of soil balls after being put into the water body. At the same time, the flourishing eukaryotic and prokaryotic microbial communities within the soil balls also enhance the structural stability of the soil balls. IEM is more suitable for small and middle size water bodies.

GAFI is a method to improve the purification speed of traditional AFI by adding a solar-powered aeration device while retaining the advantages of traditional AFI. As AFI technology, GAFI can also provide water purification, create living spaces for organisms, improve landscape and protect the shore with wave elimination effects. Therefore, we believe that GAFI can be tried to apply in lakes with large fluctuation of water level and lakes where it is difficult to restore the shore aquatic plants due to waves, or closed waters with landscape requirements. This method is very suitable for water restoration with landscape occasions. The purification efficiency of the method is very high. Aeration and planting can increase the beautification degree of water landscape to a certain extent. In order to restore the lost nature, the unit price of this method is very high. An important part of the expensive unit price is that the labor costs account for a large proportion. As long as the carrier materials were processed, its price increasing a lot accordingly. But the market in each country is different, resulting in the unit price in different countries varying greatly. As similar as GAFI, there are still many projects using CW at present. LCW has the characteristics of large buffer capacity, good treatment effect and simple process, and can also be used to improve the water quality of watershed. In a few reports, this method has been used to improve the water quality of eutrophic lakes with good effect. In particular, it gives full play to the productive potential of resources, prevents the re-pollution of the environment, obtains the best benefits of water restoration, and has higher environmental benefits, economic benefits and social benefits.

3.3.3 Comprehensive suggestions

Due to the lack of relevant information in the published literatures, we cannot make a very accurate comparison of these eight approaches. However, we made subjective evaluations of these technologies based on our experience and some published data. We believe that CB, ecohydrological restoration, geoengineering approach, IEM and the sustainable are economic relatively. If the restoration involves landscape water, GAFI or ecohydrological restoration approach can be used. When the area of the target water body is relatively large that we think it is more appropriate to choose CB or LCW. If the water body entering the lake needs further purification and has high requirements for nitrogen removal, comprehensive approach or sustainable approach can be selected. If you want to have simple equipment or tools or steps in the field that you can use the geoengineering approach or IEM method. Of course, the above suggestions are made without considering the cost of investment. Thus, the high and low costs mentioned in this article are relative comparisons among these eight technologies (e.g., the investment of these technologies are obviously cheaper compared to dredging). The specific approach selection should be considered comprehensively according to the cost requirements, hydrological conditions and site conditions.

3.4 Influence of COVID-19

3.4.1 Fecal-oral transmission

Since the COVID-19 pandemic began in 2019, it has spread to more than 200 countries, infected about 370 million people and killed more than 5 million people. In addition to conventional respiratory droplet transmission, the COVID-19 virus has now been confirmed to be transmitted by aerosol and fecal-oral route (Anderson *et al.*2020; Hindson 2020; Vardoulakis *et al.* 2022). The COVID-19 pandemic poses a significant threat and disruption to the global public health system.

Fecal-oral transmission refers to a way which the virus is excreted via defecating from a patient and then eaten by people who are vulnerable to infection through other means, leading to the spread of the disease. SARS-CoV-2 (the virus name) in COVID-19 is more infectious than SARS-CoV (the virus name) in SARS. The main performance is that it has more lasting survival activity in the external environment. Stool which is defecating into drains through toilets requires strict disinfection procedures to prevent it from entering to the water supply.

3.4.2 Transboundary rivers

River water is an important vector of virus transmission. Moreover, transboundary rivers pose a greater risk of transmission of the virus than rivers within borders, because its geographical location involving more countries. For example, In the Belt and Road Initiative, the districts that the overland Silk Road Economic Belt passing through, almost all belongs to China's international river areas. The water resources of transboundary rivers are the basis for the survival of neighboring countries and downstream countries. In order to prevent the spread of the virus among the neighboring countries through the flow of water in transboundary rivers, the protection of water sources in transboundary rivers is essential.

3.4.3 Suggestions fort transboundary water restoration

Water is key for pandemic suppression and prevention (Cooper 2020). Since the outbreak of COVID-19 in 2019, there have been few report about improving the water quality of transboundary rivers (Chakraborty *et al.* 2021a; Chakraborty *et al.* 2021b). The water quality restoration approaches of transboundary rivers during COVID-19 outbreaks, which were reported as bioremediation. This is closely related to the hydrological characteristics and pollution of rivers. In previous chapters, we have also outlined some rules and requirements for the use of biological manipulation. As the lake Vembanad in India, many of the world's long and narrow transboundary rivers also have such conditions. At present, we believe that when choosing restoration approaches for water quality of transboundary rivers, biological approaches can be chosen as far as possible, so that bacteria and viruses can be filtered more efficiently. Of course, more time and cases are needed to support this view. With the help of remote sensing images, some researchers have found that after the outbreak of the epidemic, the water quality of the severely polluted transboundary rivers have been improved due to the long-term industrial shutdown and the reduction of human activities (Yunus *et al.* 2020). This indicates that transboundary rivers have a certain self-purification ability during the lockdown, and also providing some new research clues for the water quality restoration of transboundary rivers in the future. Of course, the best approach for restoring is prevention in advance. Protection of transboundary rivers also needs to be strengthened. Countries (especially the neighboring upstream and downstream countries) that transboundary rivers pass through should cooperate with each other to build cooperation and coordination mechanism and long-term management mechanism for water resources protection of transboundary rivers. In general, it is also necessary to strengthen water monitoring and establish water environment monitoring and early warning mechanism and emergency mechanism for transboundary rivers.

4. Conclusions

Water playing an important role in people's life, is the most important and indispensable material resources for human survival and development. The review of drinking water source restoration approaches (especially innovative approaches) can strengthen the understanding of restoration principles and theories by researchers from a macro perspective, and save studying time greatly. The eight innovative approaches discussed in this paper are defined as combined implementation type and independent implementation type. They all have high efficiency for restoration, but with various investment cost and implementation difficulty. Therefore, we should choose the approach according to the suitable conditions of approaches and project budget. Meanwhile, we should choose the approach according to the suitable conditions of approaches and project budget. Meanwhile, the outbreak and epidemic of COVID-19 pose a serious challenge to the protection of drinking water sources around the world. However, there are still few literatures on the association between SARS-CoV-2 and restoration approaches, and further research in this direction can be strengthened in the future.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. A summary of studies involving the innovative restoration for eutrophic water

Approach	**BDA**	**LC**	**Effect**	**Year**	**Citation**	**SR**
Comprehensive approach	*The technical method (pipelines introducing surface water to the bottom of the lake) was combined with biological (mineralizing bacteria) and chemical (phosphorus inactivation) methods	The lake Miłkowskie, Poland	*The amount of total biogenic element amount in the lake's water volume and in the circulation of matter in water is reduced. This solution limits the development of phytoplankton	2018	(Grochowska 2020)	(Kangro *et al.* 2005; Søndergaard *et al.* 2007; Søndergaard *et al.* 2008; Dittrich *et al.* 2011; Özkundakci *et al.* 2011)

Approach	**BDA**	**LC**	**Effect**	**Year**	**Citation**	**SR**
CB	*The CB included creating submerged plant, fish, macrobenthos, and zooplankton communities	The lake Dongpo, China	*Water quality and clarity were substantially improved, and nutrient concentrations, particularly total phosphorus, total nitrogen, and Chl-a were significantly reduced	2015	(Chen *et al.* 2020b)	(Mehner *et al.* 2002; Desai *et al.* 2007; Montemezzani *et al.* 2015; Zeng *et al.* 2017; Liu *et al.* 2018; Bi *et al.* 2019; Jůza *et al.* 2019)
Ecohydrological restoration approach	*The approach included hybrid systems, SSBS, floating islands, landform adjusted shoreline vegetation and plant harvesting	The river Bzura, Poland	*Restoration improved most of the water quality indicators. 4 years after restoration, the concentrations of the total forms of nutrients and ammonium were still considerably lower than before restoration.	2013	(Jurczak *et al.* 2019a)	(Iamchaturapatr *et al.* 2007; Lynch *et al.* 2015; Zalewski 2015; Jurczak *et al.* 2018; Szklarek *et al.* 2018; Jurczak *et al.* 2019b)

Approach	BDA	LC	Effect	Year	Citation	SR
Geoengineering approach (oxygen nanobubbles)	*Oxygen-carrying materials modified from natural zeolites were used as capping agents and an oxygen-locking layer consists of oxygen-carrying materials and the oxidized sediment was formed between anoxic sediment and overlying water	The lake Taihu, China	*The DO in overlying water improved instantly from around 1.5 mg/L to 3.5-4 mg/L and 5-6 mg/L in the systems with algal blooms and without algal blooms, respectively	2017	(Zhang *et al.* 2020)	(Spears *et al.* 2014; Huser *et al.* 2016; Wang *et al.* 2020c; Patel *et al.* 2021; Zhang *et al.* 2021)
GAFI	*The GAFI was combined the advantageous components for AFI with an aerator device powered by a solar system	The lake Lize, China	*The dissolved oxygen and oxygen reduction potential were increasing when the GAFI was used, and the NH_3–N, NO_3–N and NO_2–N were effectively decreased	2012	(Lu *et al.* 2015)	(Chang *et al.* 2014a; Chang *et al.* 2014b; Chang *et al.* 2014c; Chen *et al.* 2014; Yeh *et al.* 2015; Chang *et al.* 2017; Kirimtat & Krejcar 2018; Fonseca Largo *et al.* 2020; Wang *et al.* 2020b; Li *et al.* 2021)

Approach	BDA	LC	Effect	Year	Citation	SR
IEM (Soil ball-making)	*Calcium oxide, silicon dioxide and citrate buffer were added to the soil balls to increase the hardness and pH	The wetland Dalseong, Republic of Korea	*The soil ball with 0.75 % hardener and neutral pH (pH 7.3) effectively improved the water quality of the ponds, lakes, and streams	2015	(Park *et al.* 2016)	(Szymanski & Patterson 2003; Zakaria *et al.* 2010; Shalaby 2011; Mielczarek *et al.* 2013; Sitarek *et al.* 2017; Dondajewska *et al.* 2019b; Sharip *et al.* 2020; Dobrzyński *et al.* 2022)
Sustainable approach	*Physical (hypolimnion aeration by means of wind-driven aerator), chemical (phosphorus and ammonium N precipitation with small doses of compounds) and biological methods (supportive stocking with the fry of predatory species). The direction of spring waters containing high concentration of nitrates to the deoxygenated bottom of the lake	The lake Uzarzewskie, Poland	*A reduction of the biomass as well as lower chlorophyll-a content (from *ca* 60 mg m^{-3} prior the restoration to 9-14 mg m^{-3} after 10 years) and higher water transparency (2 m on average). Cyanobacteria were replaced by diatoms, dinoflagellates and chrysophytes	2009	(Dondajewska *et al.* 2019a)	(Deppe & Benndorf 2002; Hansen *et al.* 2003; Kowalczewska-Madura *et al.* 2018; Podsiadłowski *et al.* 2018; Dondajewska-Pielka *et al.* 2020)

Approach	BDA	LC	Effect	Year	Citation	SR
LCW	*Waterflows by gravity through the marsh flow-way. It enters each of the independently operated cells via gated culverts.	The Lake Apopka, USA	*The system removed TP over annual periods. The Marsh flow way provide important functions within restoration programs that help improve eutrophic lake conditions	2003	(Dunne *et al.* 2012)	(Lee *et al.* 2009; Dunne *et al.* 2013; Martín *et al.* 2013; Yang *et al.* 2020a)

BDA represents the brief description of the approach. LC represents the location and the country of application case. Year represents the date of application case. SR represents the seminal references.

Table 2. The evaluation of the innovative approaches in Table 1.

Approach	Efficiency	Cost	Suitable goals
Comprehensive approach	High	High	*Lakes with high level of eutrophication
CB	High	Low	*The lake has a high concentration of nutrients even after seri
Ecohydrological restoration approach	High	Low	*Urban eutrophication cascade reservoirs and small urban wat
Geoengineering approach	High	Low	*Anoxic lakes that are experiencing or have experienced algal
GAFI	High	High	*Water landscapes and environmental conservation
IEM	High	Low	*Soil balls could be applied to improve water quality of small
Sustainable approach	High	Low	*The lake need to gradual reconstruct the structure and funct
LCW	High	High	*Help to improve watershed and lake water quality