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Overview on Treatment and Control Technology for Water Eutrophication

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Abstract Eutrophication is one of the important reasons for water pollution and is also the problem for water pollution treatment at home and abroad. This article takes an overview on various technical methods and their characteristics applicable for treatment and control of water eutrophication from the aspects of physics, chemistry, biochemistry and environmental factors regulation, and discusses the application and development trend for relevant technologies.

Key words Eutrophication, Water pollution, Treatment and control technology

Water eutrophication refers to the eutrophication problem appeared in the process of accelerated natural evolution of water in short time under the effects of human activities. It means a large amount of nutrient substances including nitrogen and phosphorus enter into subcritical flow water bodies such as lake, estuary and bay, resulting in excessive high concentration of nutritive salt. Under serious conditions, water eutrophication can cause algae flood called algae-type eutrophication, *i. e.* "algal bloom" or "red tide"; it may also cause overgrowth of aquatic plants called plant type eutrophication. River and lake pollution is increasing continuously in China with eutrophication problem in particularly prominent condition and the trend to be serious[1-2]. In the late 1970s, the eutrophic lakes occupied about 27% in China, in the late 1980s and early 1990, about 63% of lakes were eutrophic in China, and in late 1990s, the number reached 85%. According to *Report on the State of Environment in China* (2010), surface water pollution becomes more serious in China with the seven key river systems polluted mildly; among 26 state-controlled key lakes (reservoirs), one lake (reservoir) suffered from severe eutrophication, accounting for 3.8%; the number of moderate eutrophication ones was 2, accounting for 7.7%; the mild eutrophication ones were 11, accounting for 42.3%; and the others were all in mesotrophic, accounting for 46.2%. We take an overview on various technical methods and their characteristics applicable for treatment and control of water eutrophication from the aspects of physics, chemistry, biochemistry and environmental factors regulation, and discusse the application and development trend for relevant technologies.

1 Pollution sources control

1.1 Control of external pollution The first and crucial step for the control and treatment of lake eutrophication lies in reduction of external pollution load. To reduce or cut off the entering of external nutritive materials and prevent the external nutritive salt from entering into the water body, we can adopt such specific measures as water purification, sewage interception engineering, phosphorus restriction or prohibition in detergent, rational use of land, *etc*.

1.2 Control of internal pollution When the discharge of external pollution to the water is reduced or stopped, the bottom bud will become pollution "sources" in certain conditions but not be the "collection" of pollutants any more. At this time, the pollutants in bottom bud will be released to cause secondary pollution to the water, become internal pollution sources and accelerate the water eutrophication. The common control technologies for internal pollution include desilting and dredging, in-situ covering, bottom bud passivation[3], bioremediation, *etc*. Desilting and dredging is one of the methods to reduce internal pollution load. Dredging engineering has been performed in Lake Suwako in Japan, Lake Geerplas in Netherland and Xuanwu Lake in Nanjing trying to reduce internal pollution load in the lake; after the performance of engineering, the water quality is improved in the initial period but continues to be in eutrophication state in the later period. By *in-situ* covering technology, we can cover a layer or multilayer of coverages including clean soil, sand, sludge and gravel over the surface of bottom bud to isolate them from upper water, thus prevent the pollutants in bottom bud from moving to overlying water[4]. In Venetian Lagoons of Italy, sand coverage on bottom bud prevents the diffusion of pollutants in bottom bud effectively[5]. In-situ covering technology is characterized in easy construction and low cost compared with desilting and dredging, but the water storage will be affected for small-sized lakes and the demersal ecological environment will be broken in certain extent after the coverage of bottom bud.

2 Water treatment technology

2.1 Physical methods

2.1.1 Pollutant sluicing with diverted water and dilution. In this

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method, we can draw oligotrophic salt and good quality water into eutrophic water body, so as to scour and replace eutrophic water in the lake. Water eutrophication situation can be relieved in short time by this method, if the external and internal pollution can not be controlled effectively, the effects of pollutant sluicing with diverted water and dilution can not remain in long time and the feasibility of this method is poor in water-deficient areas such as northern areas.

2.1.2 Adsorption method. In this method, we can utilize the materials with high specific surface area to adsorb the substances including algae and suspended solids from the water, thus realizing the purification of eutrophic water. Common adsorbents include activated carbon and zeolite, sometimes, we also use coal ash, hydrotalcite and sediment as adsorbent. According to the research conducted by Wang Ying *et al*, nano activated carbon fiber can be used to remove various pollutants in eutrophication landscape water effectively[6].

2.1.3 Membrane filtration method. In this method, we can use polymeric membrane to isolate impurities such as algae from water by taking impressed pressure or chemical potential as driving force. Li Fazhan has researched ultrafiltration membrane process with other people and treated eutrophic lake water in combination with sand filtration and the comprehensive process of biological contact oxidation technology. By this combined process, the removal rate for algae can reach 97.9% with a better removal effects than regular process[7]. Membrane filtration method can deliver a high removal rate for algae and algal toxin, but the water is easy to be polluted or plugged by organic matters and the cost is high.

2.1.4 Ultraviolet Method. When the microorganisms such as algae suffer from ultraviolet irradiation, the DNA spirochete in frustule will be broken by the electromagnetism emitted by ultraviolet, resulting in the cells failing to multiplicate and achieving inactivation effects. Liu Qian has performed ultraviolet method to inactivate algae in reservoirs together with other people, the results shows that algae removal rate is 99.2% when ultraviolet radiation dose is 60 mJ/m^2[8]. Ultraviolet process for algae removal has a low operating cost and no harmful disinfection by-products will be generated by this method, but the technology is not mature in production application currently and its promotion and application is limited[9].

2.1.5 Mechanical method for algae and weeds removal. Shen Yinwu has developed mechanical removal instrument for blue-green algae which collects water rich in algae by the methods of gravity vibration, rotary vibration and centrifugation with other people, and use the instrument to treat water bloom of Dian Lake, thus delivering a better effect for cyanobacterial bloom control[10]. Shang Shiyou has performed research on moderate control for eutrophication as well as development and utilization of water plants in Ulansuhai Nur by using weed cutting machine with other people, and the research shows that biological siltation promotion speed can be slowed down by the method of cutting water plants with mechanical technology[11]. Mechanical method is an emergency treatment method, applicable for eutrophic water body with a large amount of algae and weeds, but is can not control water eutrophication fundamentally.

2.2 Chemical methods

2.2.1 Oxidation Method. Chemical oxidants can oxidize partial structure (such as pyrrole ring in chlorophyll of frustule) of frustule, disturb its normal metabolism, thus resulting inactivation and death of frustule. Common oxidants for algae control include chlorine (Cl_2), chlorine dioxide (ClO_2), hydrogen peroxide (H_2O_2), ozone (O_3), potassium permanganate ($KMnO_4$), *etc*. Pre-oxidation with chlorine (also known as prechlorination) is a traditional algae control and killing technology. However, chlorine is easy to react with organic matters in water, generating harmful by-products such as chloroform[12]. The algae removal rate of chlorine dioxide is higher than chlorine[13], and no chloroform will be generated[14]. One study shows that the algae removal rate can reach 75% when the dosage of chlorine dioxide is only 1 mg/L[15]. Potassium permanganate has an obvious suppression and removal effects on algae and microorganism in the water. According to the test conducted by Shi Ying *et al*, in simulated eutrophic water, when the dosage of complexing agent of potassium permanganate is 1 mg/L and coagulant (polyaluminium chloride) is 20 mg/L, the algae removal rate will reach 70%; but the content of manganese ion (Mn^{2+}) in the water may rise and the effluent color may increase when applying potassium permanganate and its complex reagents[16]. The problems of by-products increasing and secondary pollution will not exist when removing algae with hydrogen peroxide and the method of pre-ozonation, meanwhile, oxidation ability of these agents is stronger and efficiency for algae removal is high. But the higher production cost for these two agents restricts its promotion and application. Photocatalysis oxidant receiving more researches is titanium dioxide currently (TiO_2). When receiving the radiation of solar energy, titanium dioxide can oxidize OH^- and H_2O adsorbed in its surface into hydroxyl radical ($\cdot OH$). Strong oxidizing property of hydroxyl radical will cause the death of algae[17]. Choi has made a research on degradation effect of microcystic toxins (MC – LR) by titanium dioxide photocatalyst (N-tiO_2) with other people, they find 50% of microcystic toxins can be degraded within 30 minutes and they can be almost removed completely within 2 hours under the irradiation of visible light; the technology can treat eutrophic water body efficiently without toxicity[18]. But the photocatalytic oxidation technology of titanium dioxide is remaining in experiment research and exploration stage currently, and there is no report on its actual production and application[19].

2.2.2 Non-oxidation method.

(1) Copper sulfate. The reason for copper ion (Cu^{2+}) to produce the toxicity on algae is the copper ion has a very strong affinity with the sulfur-containing group in the surface of algae cytoderm which will disturb the normal metabolism and biochemical reaction process of the algae, thus suppressing the growth of algae. Copper sulfate ($CuSO_4$) reagent method is a mature process

commonly used in the USA and Australia to treat algae-type eutrophic water body. To prevent copper ion influencing aquatic animals, we can produce copper sulfate into copper-base compound (containing copper organic chelate), but the secondary pollution of copper may exist in this condition.

(2) Rare earth accumulation. Excessive accumulation of rare earth in frustule can suppress the growth of algae, it can increase the permeability of cell membrane, reduce the activity of enzyme and affect the synthesis of protein and nucleic acid in the cell and the secretion of hormone, thus influencing metabolism and resulting the death of algae finally[20]. High concentrations of La^{3+} and Ce^{3+} can suppress the growth of microcystis and Selenastrum capricornutum. When the mass concentration of La^{3+} and Ce^{3+} is 0.05g/L, the growth and propagation of microcystis will be suppressed completely[21]. China is rich in rare earth resources, so the cost for rare earth accumulation method to control the algae is lower, however, the rare earth element can lead ecological risk with its accumulative and amplification actions in the food chain.

2.3 Physicochemical methods

2.3.1 Coagulating sedimentation. Add coagulant into the algae-type eutrophic water body, then the hydrolysate of coagulant will neutralize with particulate matters in the water such as algae electrically and destablize and the larger alum floc will be formed by the adsorption bridge between small alum flocs or the action of adhesion net, finally, the pollutants such as algae will be sedimented and removed under the action of gravity. Coagulants used for the control of eutrophic water body include iron-based coagulant, aluminum-based coagulant, clay, *etc.*, among which the application of iron-based coagulant and aluminum-based coagulant is most general.

(1) Iron-based coagulant. Iron-based coagulants include ferric chloride, polymerization ferric chloride, PFP, PFSS, *etc.* Xiao Lijuan et al have conducted emergency treatment on a South China-based water supply reservoir which has water bloom by using inorganic flocculant (HA1) with ferric salt as the core. The results show that removal rates for dominant species of blue-green algae and water bloom (anabaena circinalis and microcystis) both exceed 90%[22]. Ferrate has multiple algae removal functions including oxidation, coagulation and sedimentation, and it also has the advantages of low additive dosage, instant effect and high algae removal efficiency when removing algae. But the preparation process of high-purity solid ferrate is rigor and the production cost is high, and the general ferric salt flocculant also has the disadvantages of high effluent color and equipment corrosion.

(2) Aluminum-based coagulant. Aluminum-based coagulants include alums, PASS, *etc.* After Kasper added alums into Lake Sonderby, the total phosphorus of lake water was down to 0.02 mg/L from 1.28 mg/L, and the transparency lake water increase to 1.5 m from 0.8m[23]. Alums and alum pulp are different from the traditional algicides such as copper sulfate, they will not form large-sized dead algae and floating membrane and threaten the living of fishes and zooplankton directly when removing algae. But the usage amount of this agentia is large and the accumulation of aluminum ion in human body may cause toxic symptom[24], so it is not applicable for water bloom control in large-scaled eutrophic water body.

(3) Clay. Clay can disperse in the water to form a large amount of suspended particles which will collide and assemble with frustule, then settle in the bottom of water under the action of gravity. After adding a kind of improved clay into eutrophic water body, Malcolm found the concentration of soluble labile phosphorus decreased in the water and the water bloom has been suppressed effectively[25]. The sources of clay are sufficient with easy using method and low cost. Its flocculation has the features of safety and non-toxic. However, clay algae removal technology has been limited to make research and local emergency treatment for seawater red tide so far, it is rarely seen in the application of fresh water bloom.

2.3.2 Air flotation. In air flotation method, highly dispersed microbubble will be used as carrier to adsorb suspended solids and algae in waste water, so as to make their density less than water and make them rise above the surface of water, thus realizing solid-liquid separation. After treating eutrophic landscape water body by coagulation air flotation method, Zheng Guanghong found the removal rates for algae, turbidity and TP were all above 74.9%[26]. Currently, the treatment effects for low-temperature, low-turbidity and algae-rich water body are better when using air flotation technology; but when the turbidity is above 100 NTU, slag-falling will be difficult and effluent will be unstable[27].

2.3.3 Algae control by straw. In eutrophic water body, adding straw such as barley straw, wheat straw and rice straw can cause the concentration changes of inorganic nitrogen, inorganic phosphorus and CO_2 in the water, and the changes of water transparency and light transmittance, thus influencing the growth condition of algae. Some straw can release allelochemical, for example, barley straw can release aromatic organic compounds to suppress the growth of algae. The test performed by Ball shows that the concentration of Chla can maintain at the level of 40 μg/L after adding barley straw into the lake region[28]. Raw material sources for algae control by straw are extensive and the treatment cost is low, but it has a long action period and affects the beauty of water body.

2.3.4 Electrochemical process. By electrochemical algae removal technology, we can utilize reactive oxygen ($\cdot OH$, O_2, O_3, H_2O_2, *etc.*) generated by electrochemical method in the water body to remove algae rapidly, and a certain continuous algae removal ability will remain after cutting of the electricity. Wu Xingwu adopts electrochemical method to treat algae-type eutrophic water body with other people respectively, and they all reach a better removal effect[29-30]. Electrochemical method can deliver a good algae removal effect, but the mechanism has not been clear. Therefore, the effect of equipment is unstable during actual application with large power consumption.

2.3.5 Ultrasonic method. Ultrasonic wave has the effects of mechanical vibration, acoustic streaming and cavitation which can cause the damage, breakage or shattering of biologic cell tissue. AHN has made a research on the suppression action of ultrasonic wave to algae in laboratory and shallow lake respectively with other people, the results show ultrasonic wave has a great suppression effect on the growth of blue-green algae[31]. Because ultrasonic algae removal method can result in water temperature rise in local water region and high energy consumption, and it also can affect the growth of aquatic animals, its widespread promotion is limited.

2.4 Biological methods

2.4.1 Aquatic plant remediation. Aquatic plant remediation technology refers to recover aquatic vegetation in water ecosystem, thus realizing the adsorption, utilization or transfer of nutritive salt, heavy metal and organic pollutants by the plant. Meanwhile, aquatic plants can provide attachment and mutualistic space for microorganisms, supply food sources for aquatic animals. Therefore, optimum material circulation and energy flow of water ecosystem can be realized. In addition, some aquatic plants can secrete allelochemical to suppress the growth of algae, and plant ecosystem between water and land also has the functions of trapping and filtering overland runoff, so as to maintain relative independence and stability of lake. Currently, in the aspect of eutrophication remediation, the aquatic plants under more researches include emergent aquatic plants, floating plants, floating leaf plants, submerged plant, *etc*. Emergent aquatic plants and floating leaf plants not only have high adsorption effect of nitrogen and phosphorus, but also can deliver better landscape, therefore, these plants are more extensively used in the research and application of eutrophic water body remediation. All submerged plants are located in the water, they can adsorb nutritive matters such as nitrogen and phosphorus efficiently, so they are becoming research hot points gradually. The enclosure test conducted by Wu Zhenbin and others in East Lake of Wuhan demonstrated that the rebuilt submerged plant system can improve water quality obviously, increase water transparency and maintain COD and BOD at about 20 and 5 mg/L respectively[32]. Aquatic plant remediation system adopts the sun as energy source and has the features of safety, low cost, ecological harmony and environment beautifying[33], but its acting time is long and it is difficult to control biomass and perfect ecological stability.

2.4.2 Aquatic animal control. Aquatic animal control method means to adopt manual control measures such as zoobenthos, zooplankton and fishes, utilize the predation and competition relationship between aquatic animals, give full play of the mutual dependent and restraint relation between aquatic plants and aquatic animals which act as consumers and producers and form a complete ecological food chain and food web to control the eutrophication of water body. Currently, the aquatic animals used mostly in this technology include mussel, snails, herbivorous fish, omnivorous fish, *etc*. Lu Kaihong has put some tilapia into lunar lacus with phytoplankton bloom and some water bodies in town parks with others, the results of this test show that grazing pressure of tilapia leads the decrease of chlorophyll in water body and the increase of transparency, thus controlling blue-green algae bloom effectively[34]. However, it is difficult to control the fish and zooplankton to eat algae and the introduction of adventives has the risk of initiating ecological problem. Furthermore, the effect of algae control with aquatic animals is slower than physical method and chemical method.

2.4.3 Wetland ecoengineering. Wetland has a strong ability to remove nutritive matters such as nitrogen and phosphorus from eutrophic water body. The study conducted by Yan Li and others shows that the removal rate for total phosphorus is 35.1% to 65.3%, and for total nitrogen is 28.7% to 62.9%[35] when using level three artificial wetland which consists of gravel, zeolite and fly ash packing to remove them. According to the research made by Vellidis and others, wetland can remove 78% of nitrate nitrogen (NO_3-N), 52% of ammonia nitrogen and above 66% of dissolved reactive phosphorus (DRP) and total phosphorus (TP)[36]. Compared with other methods used for eutrophic water body treatment, wetland ecoengineering has the advantages of small energy consumption, low cost and better treatment effect, and it has little pollution to the environment and is in favor of resources and the improvement of overall ecological environment. But it occupies large area and its purifying ability is vulnerable to seasonal restrictions in northern areas.

2.4.4 Artificial biological floating bed/mattress. The definition of artificial biological floating bed is planting the advanced aquatic plants or improved terrestrial plant on the surface of eutrophic water body when taking floating bed as the carrier. Artificial biological floating bed technology can realize the effect of purifying water and create water landscape at the same time. According to the research made by Guo Peiyong and others, the removal rate for ammonia nitrogen can reach 95.89% when using the floating bed system which has 30% of water surface coverage and takes ryegrass as main plants[37]. The main body of artificial biological mattress is submerged plant. Li Jinzhong has performed one-year operation monitoring on artificial mattress demonstration project in outer ring river of Tianjin Municipality with others, and the research results show that the COD removal rate by artificial mattress can reach 30% to 35% during growth period of plants when the residence time is 6 days[38]. Artificial biological floating bed/mattress can used to increase planting area of aquatic plants, enhance removal amount of nutritive matters such as excess nitrogen and phosphorus in the water, increase adhesion space for aquatic animals and microorganism as well as improve removal efficiency of pollutants. But the type selection of plants and the optimum configuration of the cenosis in this technology need to be studied further, meanwhile, the resistance to corrosion and wave of the plant vector need to be improved further.

2.4.5 Microorganism remediation. By this technology, we can establish micro-ecosystem with microorganism to accelerate material circulation and energy flow in the water and intensify their efficient adsorption and degradation actions to pollutants in the water[39], thus realizing the control for water eutrophication. Effective microbial flora (EM) is microorganism remediation flora more commonly used for eutrophic water body. The flora is cultivated by photosynthetic bacteria, lactic acid bacteria, saccharomycetes, actinomycetes and fermentation type filamentous bacteria. In addition, another commonly used flora belongs to relatively single microorganism remediation flora, such as Nocard's bacillus (Nocardia), photosynthetic bacteria (PSB), Clear-Flo series bacteria, *etc*. After purifying the eutrophic lake water with immobilized multiplication nitrogen cycling bacteria, Li Zhengkui found that the total nitrogen decreased 75%, ammonia nitrogen decreased 91.5%, COD decreased 75% and the water quality has got improved obviously after treatment[40]. Compared with traditional processes, microorganism remediation technology for eutrophic water body has such advantages as low treating cost, easy operation, little secondary pollution, remarkable ecological comprehensive benefit and outstanding treatment effect[41]. But it is difficult to establish the system to analyze the correlation between all water quality changes and microorganism under different water conditions now.

2.4.6 Algae control with beneficial algae. Algae control with beneficial algae is to control the flood of harmful algae by utilizing controllable algae and inter-specific competition principle, so as to realize the control of water bloom. Hydrodictyon is large-sized meshes and mesh bag-shape green algae which is visible to the naked eyes and has strong reproductive capacity, it can adsorb a large amount of ammonia nitrogen, nitrate nitrogen and inorganic phosphorus during growth period to reduce nitrogen and phosphorus content in eutrophic water body, make blue-green algae fail to reproduce abundantly in water body due to lost high-nutritive condition they lived on, thus achieving the purpose of controlling algae with algae[42]. According to the research conducted by Zhao Kun and others, Hydrodictyon has a stronger control action on microcystis aeruginosa. After the planting time for hydrodictyon reached 8 days, the death rate for microcystis aeruginosa can achieve 92%[43].

2.4.7 Cyanophage. Cyanophage is vrioplankton group (also called as blue-green algae virus) taking blue-green algae as host. It is a potential control factor for "water bloom" of blue-green algae because it can infect blue-green algae specially and cause their death[44]. For example, the extinction of Lyngbya majuscula water bloom in Moreton Bay of Australia has the relation with Cyanophage[45]. But there is no report on water control practice with Cyanophage currently.

2.5 Control method with environmental factors Algae and aquatic plants can be affected by the environmental factors such as dissolved oxygen, hydrodynamic condition, pH, illumination and water temperature, according to this, properly controlling environmental factors in water body can suppress the growth of algae and flood of aquatic plants in a certain extent. Increasing dissolved oxygen content in the water can recover and strengthen aerobe's ability to degrade pollutants in the water, as well as accelerate adsorption and conversion efficiency of nitrogen and phosphorus. According to the research made by Lin Jianwei and others, aeration can used to control the release of total phosphorus in bottom mud effectively, thus realizing the control for limiting factor (phosphorus) on the growth of algae[46]. Aeration method can deliver a remarkable effect on the remediation of urban landscape water body and the resolving of water blackening and smell. Hydrodynamic condition is an important factor to influence eutrophication condition of water body and water bloom. Therefore, increasing the flowing speed of water body can suppress the growth of algae and postpone the occurrence of water bloom in a certain extent[47]. Wang Lili has analyzed the effects of algae under different flowing speeds in small-sized river course, and the results show that when the flowing speed $v \leqslant 0.08$ m/s, the content of Chla increases with the increase of flowing speed; when $v > 0.10$ m/s, the content of Chla decreases with the increase of flowing speed[48]. To increase water flowability of general urban landscape water body, it is necessary to add some facilities such as large power circulating pump, and this will result in large energy consumption. The changes of water level can bring changes to underwater illumination and dissolved oxygen level, so we can change submerged plant community to make influence on the growth of flush submerged plants in weed-type eutrophic water body. According to the research made by Richardson and others, the changes of lake water quality and phytoplankton are not obvious during the course of water level lowering and after the lowering, but the biomass and coverage of most floating leaf plants and submerged plants decrease remarkably[49]. Put shading blankets such as fixed blanket and moving blanket under the water to weaken the illumination needed by aquatic plants or algae. This method can deliver an obvious effect on the density reduction of algae and flush waterweed[50]. But the extensive application of this new technology is limited due to high cost and short life of shading material.

3 Development trend of treatment technology for water eutrophication

From the current situation, there isn't any single method capable of removing the nutritive matters such as nitrogen and phosphorus from water body whether in domestic or foreign so as to realize the control for water eutrophication; but in the long term, to realize sustainable development, it is necessary to research and develop a composite technical system taking biotechnology as main body in combination with multiple technologies including physical, chemical, materialization and environmental factor controlling.

4 Conclusions

On one hand, the nature and human environments the water body in the world is in are of all kinds, the size, depth, age and function of the water bodies differ from one another, and the contamination degrees and the reasons for eutrophication have great difference; on the other hand, the mechanism of eutrophication has not been studied thoroughly[51]; moreover, each technology for water eutrophication control and treatment has its own good point. Therefore, we should control and treat water eutrophication according to local conditions and multiple references, meanwhile, we should also explore new technology audaciously to solve the environment treatment problem better.

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uation method is only suitable for a local region at present, and there is no comprehensive assessment of a large-scale area, mainly showing that basic work of assessment is not complete, and it is difficult to determine evaluation standards. In addition, limited by the display scale of database and geographical information system, refined analysis of risk zoning was not carried out in this research, which needs to be studied further.

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