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Water quality model for the influence of riparian materials on the purification ability of riverine organic pollutants[1]

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Abstract. Because China has only focused on economic development but ignored environmental protection in the past few decades, which has caused serious water pollution and water shortage in China. Rivers are flooded with all kinds of pollutants, including organic pollutants. In this paper, the construction of water quality model for the influence of riparian materials on the purification ability of riverine organic pollutants was studied. The present situation of water pollution in China was first introduced, and then the process of constructing water quality model which affected the purification ability of organic pollutants was studied, finally, the water quality model was established for ecological river course. Correlation analysis shows that organic pollutants are similar to model parameter coefficients, and the model can accurately reflect the overall purification ability of riparian materials to organic pollutants in water.

Key words. River water quality model, organic pollutants, riparian materials, ecological river course.

1. Introduction

In recent years, the importance of river ecology has been widely recognized, concept of river hardening has been abandoned gradually, and the ecological river channel has been introduced into the river improvement project, more attention has been paid to the study of quality of river water in rivers and streams, and the results have showed the influence of ecological river channel mechanism. However, there is little research on riparian water quality models, and there is no reliable

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mathematical model to explain the impact of riparian resources on water quality. The mature water quality model can be used to simulate the characteristics and rules of water pollutants migration and transformation, and study the influence of pollutants on water quality development. According to the mechanism of river bed degradation affecting organic pollutants in water bodies, the river water quality model issued by the International Water Association was simplified, and the river water quality model was simplified to simulate the different ecological processes. In addition to the degradation of organic pollutants, references can be provided for water environment pollution control planning and decision analysis to improve the existing river water quality model, and evaluate the ecological effects of rivers.

2. State of the art

Ecological restoration of rivers refers to the restoration of rivers by means of integrated methods, resulting in the loss or degradation of natural functions [1]. At present, the ecological restoration methods at home and abroad are mainly physical methods, chemical methods and biological ecology methods, some successes in pollution control of rivers are achieved. Physical means mainly refers to sediment dredging, machinery, algae and so on, this method can quickly deal with the eutrophication of rivers in the short term, however, because the process of pollutants itself will not degenerate and transform, this method is often used to cure and cannot completely improve the water environment [2]. Chemical methods, such as condensation, precipitation, chemical removal of algae, the chemical method is faster than the physical remediation method, and the operation is more convenient [3]. But a lot of drugs can cause damage to rivers in other organisms, causing two pollution, the repeated use of drugs can cause resistance to water in algae and affect treatment outcomes [4]. In recent years, the method of biological ecological restoration is a fast developing new technology, and it is also one of the hot spots of scholars at home and abroad [5]. The purpose is to realize purification pollution of the river water by using the water purification facilities in the river space with the advantages of good effect, low cost, low energy consumption and low running cost. The viewpoint of ecology and ecological restoration technology is starting from the overall optimization of the ecological system to gradually restore damaged ecosystems, improve water purification capacity, improve the water quality of the environment, and establish a healthy aquatic ecosystems [6]. Usually the cultured plants or inoculated microorganisms are used for life activities; pollutants in the water are transferred, transformed and degraded so that water can be purified. Ecological restoration of landscape water technology includes: channel aeration technique, microbial enhancement techniques (bacteria), biofilm technology and biological contact oxidation process, constructed wetland technology, pond stabilization techniques and aquatic phytoremediation techniques.

3. Methodology

It is generally believed that rivers are naturally flowing water that has a considerable amount of water on its surface or perennial or seasonal. Some scholars believe that the urban river water environment covers the city's linear water (natural rivers, artificial channels, and moat) and the composition of the water cycle space. Compared with natural rivers, urban rivers and regional human activities interact greatly [7]. On the one hand, the region's healthy rivers provide a variety of services for socio-economic activities [8]. On the other hand, the river water, water cycle, water quality, health conditions are also affected by high-intensity social and economic activities. With the rapid growth of population and the rapid development of economy, more and more pollutants are discharged into rivers, much more than the self-purification capacity of rivers [9]. In addition, due to changes in environmental conditions, river pollutants enter the river bed sediments, with the river water temperature, change of pH and biodegradation, the function of water flow back to the river makes it difficult to control the source of pollution, the concentration of dissolved oxygen in highly polluted river water is very low, or even zero, which causes the smell of rivers, or even massive death of fish, and seriously damages the river's ecosystem. The specific pollution phenomenon is shown in Fig. 1.

Fig. 1. Current situation of organic pollution in rivers

The total amount of industrial wastewater and domestic wastewater has reached more than 5000 tons, and many rivers have become the retention areas of sewage [10]. The total length of rivers in the United States is about 420 thousand km, accounting for about 29 % of the river pollution. The content of pesticides, phenol, arsenic, mercury, and chloride in the famous Mississippi River far exceeds the required standard, the turbidity and the smell of black of the river lead to the extinction of many aquatic animals. Half of the main river suffers serious damage, and rare shrimp is near extinction due to serious water pollution. Rivers in China are also seriously polluted. According to China's environmental status bulletin issued by the State Environmental Protection Administration in 2012: the pollution cross section ratio of Yangtze River, the Yellow River, the Pearl River, Songhua River, Huaihe River, Haihe River, Liaohe River, Zhejiang Minji River, Northwest River and Southwest River was about 20.9, rivers in China's cities were experiencing a series of environmental problems with the rapid development of cities. At present, more than 80 % of the city's rivers are polluted. The problems of water pollution and ecological degradation in China's urban rivers highlight the deterioration of the water quality and even the stench of life, water ecology is seriously degraded and even destroyed, the dike art and river geometry, urban flood, and river landscape are greatly hurt. In short, urban rivers in China are faced with a variety of environmental problems, as shown in Table 1.

Table 1. Results statistics of watershed segmentation

The impact of accelerated urbanization	With the accelerated pace of urbanization, a large number of industrial waste water and some domestic sewage are discharged directly (or not up to standard) to the river without treatment, resulting in serious pollution of water quality, and COD, BODS, ammonia nitrogen, total nitrogen and total phosphorus exceed the standard.
The effect of one-sided pursuit of function	In the process of urban construction, only the flood control function of the river channel or the beautification function of the river channel are taken into account, but the resources functions and ecological functions of the river course are ignored, bending and straightening, stone revetment and high building are adopted.
The influence of river bank hardening on channelization	Many of the city's black odor rivers covered the underground river, the hardening and channelization of the river banks lead to the loss of water space, which reduces the habitat of aquatic organisms and has many negative impacts.

In this paper, RW QM 1 model is studied. The components involved in the RW QM 1 model are complex, and their mathematical models are more complex, and it is difficult to apply the full model directly to practice. Therefore, the RW QM 1 model is simplified for the problems that need to be addressed in this study. Preliminary studies show that riparian substances have important effects on microbial biomass and enzyme activities, which will affect the enzyme activities of microbial biomass and key biochemical reactions such as nitration, and affect the degradation of organic pollutants in rivers. Therefore, it is assumed that the degradation process of organic pollutants is only related to suspended bacteria, the effects of algae and plankton are ignored. Based on the RW QM 1 model, it is necessary to establish a solution containing biodegradable dissolved organic matter, and seven components and six biochemical reactions such as heterotrophic bacteria, ammonia nitrogen, nitrite nitrogen, nitric acid nitrogen, dissolved inorganic phosphorus, and dissolved oxygen. River biochemical reaction model is simplified. S-RW QM 1 control equation is selected for the continuous mixing reaction tank (CSTR)

$$\frac{\partial c}{\partial t} = \frac{Q}{V}(c - d)\,, \tag{1}$$

where Q is the influent flow, V is the volume of the reach, c is the concentration of the influent concentration, and d is the component effluent concentration. The upper formula is the rate equation of component transformation process.

Organic pollutants are characterized by TOC, in RWQM 1 model, COD is expressed as organic matter, and the RWQM 1 model is used to classify COD components. The model converts conventional COD data into component data that meets the model requirements. TOC COD Total organic carbon (TOC) is an indicator of the total amount of organic matter in carbon bodies. Chemical oxygen demand is the amount of oxidant consumed by the reducing substance in the water that is easily oxidized by the strong oxidizing agent; the results are expressed in terms of oxygen content. In the river body, the composition of the reducing material is relatively stable, or the proportion of inorganic reducing substances in COD is small, the change is not enough to cause the linear relationship between COD, TOC and COD can be used, TOC data can enter the model's available COD data. In the present study, the experiment was conducted with water obtained from the new port of Guangzhou; the TOC content of the river was stable at 21.01 to 24.99 mg/l, COD and TO were used to analyze six batches of water samples, content of organic pollutants in experimental water. The results of linear regression analysis, detection and regression analysis are shown in Table 2 and Table 3.

Table 2. Content of organic pollutants in experimental water

TOC	COD1
20.03	23.63
20.39	24.58
20.83	29.63
20.64	31.25

Due to the lack of simple and effective heterotrophic bacterial methods, hypothesis modeling was commonly used in model simulations. In this study, COD accounted for 10 % of the total COD. The reduction rate of COD in the experimental water body reached 94 %, and the inert organic matter S was 6 % of the total COD.

The content of ammonia nitrogen in the experimental water was 0.41∼0.54 mg/L, the content of nitrate nitrogen was 1.04∼1.35 mg/L, content of nitrite nitrogen was 0.11 to 0.18 mg/L, the proportion of organic nitrogen that accounted for 80 total phosphorus percentage was neglected, with a content of 0.45 to 0.54 mg/L.

Table 3. Linear regression analysis of TOC and COD

R	Standard error	P	Regression constant	Regression coefficient
0.8536	0.2363	0.0086	15.3665	0.5693

The model stoichiometry and kinetic parameters used in this study were based on the typical values given by the International Water Association (IWA) as the initial values of the simulations. Sensitivity analysis was used to analyze the effect of parameter variations on the results. According to the hydrophilicity of different riparian materials, it can be seen that microbial biomass and adjustment of MK/UQ value can affect the kinetic parameters of simulated COD values and improve the accuracy of simplified RW QM 1 model. The sensitivity was calculated by the formula

$$S = \frac{Y - X}{X}, \tag{2}$$

where S is the sensitivity and Y, X are the concentrations of components before and after the change of kinetic parameters. When S is greater than 1, the parameter values have a great influence on the computation results of the model components.

The ecological riparian based on the ecological characteristics is the main ecological problem of riparian. According to the basic principle of ecology, the river construction of ecological riparian comprehensive evaluation index and evaluation method was discussed, and some technical extension systems of urban ecological riparian construction in the middle reaches of the Yangtze River were summarized. Most ecological riparian ecological problems are mainly reflected in the destruction of ecological balance, low plant diversity, river heterogeneity decreased in the case of serious water pollution. The principle of ecological river bank planning should not only follow the principles of nature and rational allocation of plants to avoid biological invasion, maintain sustainable development and unity, but also increase the riparian hydrophilic space, strengthen the comprehensive management of rivers, parks and surrounding parks, and form distinctive waterfront landscape according to the natural characteristics of the original river bank and ecological problems. In the ecological river bank planning and construction, the engineering measures and plant measures should be organically integrated. Species and communities are the main considerations for the restoration of aquatic vegetation in the construction of riparian ecosystems. Selection of species and allocation of community are one of the key factors for the success of vegetation restoration. The choice of pioneer species is to screen species that are tolerant and adapted to river water quality as a pioneer species in restoration of aquatic plant communities on the basis of biological characteristics and pollution tolerance of aquatic plants, at the same time, community species are provided for the restoration of communities. In combination with domestic and international studies on the ecological management of aquatic plants in lakes and rivers, the pioneer species of aquatic plant communities should comply with the following principles. The ecological disasters caused by improper species selection have many precedents in China, the ecological safety of species is considered, in principle, it's generally possible to consider local or existing species or historical species (including the introduced species that grow safely) as pioneer species and constructive species. The selected species should have better adaptability to climate and water temperature in the river basin, plants with strong reproductive ability, resistance to wind and waves, low transparency requirements, and adapted to the survival of deep water are selected. In the process of water ecological restoration, there are many adverse habitats such as high pollution load, large phytoplankton reproduction and single spatial structure of communities. Therefore, pioneer plants must have a strong ability to resist pollution, survive and grow in harsh polluted water bodies, and form a fixed community.

Plant design has been applied to native trees. The banks of the park will be divided into different functional departments. Upstream can be designed for use in water management areas, water management area retains the original dike foundation and returns along the road, the original vertical embankment can be used to enter the planting pool, at the side of the dam, hydrophilic area is designed in high cruise terminal, the hydrophilic area retains the original cement embankment foundation and returns along the road, the planting area is formed in the original vertical embankment slope soil, and pebbles are laid on the embankment to form a hydrophilic interface, the water level is above the water level platform. The lower reaches are designed as play areas, the iris is planted to form obstacles of wind and waves, the original pieces are transformed into embankment to reduce the slope of the river bank and form a gentle slope, lawns and local plants are planted, visitors can close hydrophilic footprint of low water network at the interface of water, as the scene designed in Fig. 2.

4. Result analysis and discussion

The content of lipid, metabolic state and organic pollutant of microorganisms in the experimental water was simulated at the end of the river circulation. The results show that microbial biomass, dehydrogenase, fluorescein, ethylidene diacetate and nitrate reductase activities are significantly different under the influence of different river bed materials. The enzymes involved in microbial, nitrifying, and other key biochemical reactions differ in their activity, so that degradation of organic pollutants in rivers is different. The mole ratio of methyl naphthoquinone and ubiquinone can reflect the metabolic state of microorganism, the higher the ratio is, the more pronounced anaerobic metabolism will be. From the experimental results, it is can be seen that the better the hydrophilicity of the riparian materials is, the higher the microbial biomass will be, and the lower value of the aerobic metabolism is, the higher the degradation rate of organic pollutants will be. The characteristics of the West Jinye filler affect the growth of microorganisms on their surfaces. In the three fillers of Gebin Bank, the pebbles are porous, the most sediment in the

Gobbin structure can provide the largest surface area for microorganisms, and is more conducive to the growth and reproduction of microorganisms. The larger microbial biomass per unit volume of filler leads to higher dehydrogenase activity, resulting in a strong degradation of organic pollutants. It can be seen that the kinetic parameters which affect the biodegradation of organic compounds in the COD component of RW QM 1 are microbial biomass. According to the results of microbial biomass, MK/UQ and sensitivity analysis, the constants of aerobic growth rate of heterotrophic bacteria and the constants of aerobic absorption rate of heterotrophic bacteria were investigated respectively; the simulation accuracy was improved by constant value calculation. The results are shown in Table 4.

Fig. 2. Ideal state after processing

Table 4. Results of simulation calculations

Category	Material	End time of the run cycle	Simulated value after check	Fractional error
Riparian materials	Permeable brick	60.36	57.36	–2.36
	Pine wood chips	46.36	59.36	–3.35
Gabion revetment	Granite	17.86	17.56	5.36
	Pebbles	12.96	16.34	6.31

After adjusting the kinetic parameters, the relative error between the COD simulation value and the measured value during the operation of the river channel was small. Model parameters and the content of microbial lipids, and the relationship between MK/UQ molar ratio and organic pollutant were analyzed. Correlation analysis shows that microbial index is highly correlated with organic matter and riparian matter; it is consistent with the degradation of organic pollutants in rivers. Therefore, the model can reflect the influence of riparian substances on the purification ability of organic pollutants in water, and simulate the degradation of organic pollutants in rivers.

5. Conclusion

In this paper, in view of the degradation mechanism of organic pollutants in the water body, the river simulation results of "simplified river water quality model 1" (S-RW QM 1) based on river water quality model 1 (RW QM 1) were established to simulate the process of biochemical reaction and degradation of organic pollutants in riverbed. After adjusting the relative parameters, it can be found that the relative error of COD simulation is small; S-RW QM 1 has good simulation results. In addition, sensitivity analysis of the kinetic parameters indicates that the parameter affecting the COD fraction simulation is molar ratio. According to the influence of riparian resources on microbial biomass and metabolic status, the adjustment of the molar ratio can improve the accuracy of COD simulation. S-RW QM 1 can reflect the effects of riparian substances on the purification ability of organic pollutants in water, and simulate the degradation of organic pollutants in rivers. There are still some shortcomings in this study because of the limited time and ability, for example, the results of this study may not be suitable for other areas due to the imbalance in the level of organic pollution in rivers, and the further research is needed.

References

[1] Y. Wang, P. Wang, Y. Bai: *Assessment of surface water quality via multivariate statistical techniques: A case study of the Songhua river Harbin region, China.* Journal of Hydro-environment Research *7* (2013), No. 1, 30–40.

[2] J. Qu, M. Fan: *The current state of water quality and technology development for water pollution control in China.* Critical Reviews in Environmental Science and Technology *40* (2010), No. 6, 519–560.

[3] B. Spänhoff, R. Bischof, A. Böhme, S. Lorenz, K. Neumeister, A. Nöthlich, K. Küsel: *Assessing the impact of effluents from a modern wastewater treatment plant on breakdown of coarse particulate organic matter and benthic macroinvertebrates in a lowland river.* Water, Air, and Soil Pollution *180* (2007), Nos. 1–4, 119–129.

[4] J. Soininen: *Responses of epilithic diatom communities to environmental gradients in some Finnish rivers.* International Review of Hydrobiology *87* (2002), No. 1, 11–24.

[5] R. C. Nijboer, P. F. M. Verdonschot: *Variable selection for modelling effects of eutrophication on stream and river ecosystems.* Ecological Modelling *177* (2004), Nos. 1–1, 17–39.

[6] R. F. Spalding, M. E. Exner: *Occurrence of nitrate in groundwater: A review.* Journal of environmental quality *22* (1993), No. 3, 392–402.

[7] P. F. Wang, X. R. Wang, C. Wang: *Experiment of impact of river hydraulic char-*

acteristics on nutrients purification coefficient. Journal of Hydrodynamics, Ser. B *19* (2007), No. 3, 387–393.

[8] F. Wang, J. K. Burton: *Second life in education: A review of publications from its launch to 2011*. British Journal of Educational Technology *44* (2013), No. 3, 357–371.

[9] E. O. Igbinosa, A. I. Okoh: *Impact of discharge wastewater effluents on the physico-chemical qualities of a receiving watershed in a typical rural community*. International Journal of Environmental Science & Technology *6* (2009), No. 2, 175–182.

[10] D. F. Juang, W. P. Tsai, W. K. Liu: *Treatment of polluted river water by a gravel contact oxidation system constructed under riverbed*. International Journal of Environmental Science & Technology *5* (2008), No. 3, 305–314.

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