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Estimation and Impact Factor of Pathogens in the Lijiang River Using Water Quality Modeling

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Abstract

The pathogen plays an important role in spreading infection and bad impact on the public health of the river. Therefore, water quality as a model is used to simulate the spreading and fate of the pathogen in Lijiang River, it is located in Lijiang City, Yunnan Province, China (100˚25'E, 26˚86'N). Even at low bacterial levels, there is a risk of pathogens in the Lijiang River ecosystem. The water quality model results showed that the spatiotemporal (space and time) migration of pathogenic bacteria in Lijiang River from 2005 to 2015 was quantitatively revealed by the model simulation. The simulation results also showed that the transports of pathogenic bacteria in Lijiang River are extremely sensitive to the speed distribution and seasonal temperature characteristics. The study found that the rising water temperature in spring leads to a sharp rise in the concentration of pathogenic bacteria. When the water temperature is low in winter, the simulated pathogenic bacteria are relatively stable, which is lower than the concentration of pathogenic bacteria at high temperature. If the spring water temperature rises, the flow rate increases, the concentration of pathogenic bacteria accordingly increases. This research recommends the development of best management practices to control microbial growth in river basins.

Keywords

Pathogen, Water Quality, Velocity, Temperature

1. Introduction

Pathogen contamination of water systems is a major public health challenge, especially in developing countries globally [1] [2] [3] [4]. Human health-related pathogens differ in different aquatic systems, depending on the nature of the pathogen source and the intended use of the water [5]. Some literatures applied the related research of pathogen monitoring in summer and winter to the detection of river pathogen [6] [7] [8]. Other methods concentrate on further investigate and monitor the pathogen [9].

However, research using numerical models to enhance existing pathogen surveillance is still weak. In particular, the discussion of pathogenic factors has not been investigated. Specifically, the pathogen processes that affect the fate and distribution of microbes need to be well identified, and considerable uncertainty remains regarding the relative importance of each process and the spatial and temporal variability that exists throughout the system [5] [10]. In addition, how pathogen dynamics change in detail between different systems, varying in their load, point source or non-point source, temperature states are still elusive.

Furthermore, to our knowledge, no studies have found the presence of pathogenic bacteria transportation in Lijiang River in China. A very promising model making tool is becoming more and more widespread, as they can highlight the processes by which pathogens control biological dynamics and can be used to fill knowledge gaps, test different scenarios, or examine their influencing factor interventions [1]. Several different scenarios have been used to simulate pathogen contamination at different loads and temperatures in different seasons, including summer and winter [5] [10]. In addition, the effects of point sources and non-point sources are discussed using model making tool as well [10] [11]. The source of pathogens may be wastewater discharge, freshwater output, the presence or sediment of waterfowl, or the re-suspension of bacteria in the dry line, all of which may influence the results of this study [5] [10] [11] [12] [13]. Through further study, local watershed differences may be due to different pathogen loads in runoff entering rivers, as well as dilution and transport of runoff or emissions when entering rivers [1] [12] [14] [15] [16].

In recent years, with the rapid urbanization along the Lijiang River and the development of tourism, leisure users' investment in lakes and rivers will also lead to a significant increase in pathogen concentration [17] [18]. However, studies on pathogen pollution in rivers are limited, especially in the Lijiang River. Therefore, it is urgent to combine the monitoring and modeling methods to study the pathogenic bacteria in this area. For health and safety purposes, the main monitoring indicators will be coliforms (fecal coliforms and *E. coli* are the most common as proxy species). Of the serotypes of *E. coli*, O157:H7 is present in sewage contaminated water and is usually of greatest concern to people who meet these waters through drinking, swimming, or eating shellfish [19]. The aim of the present study is to select two representative indicators (fecal coliforms and *E. coli*) and combined with numerical models to enhance the monitoring of existing pathogens. Furthermore, the discussion of impact factors such as temperature and flow rate will be investigated. This study will help us better understand the impact of pathogens on river ecosystems and fundamentally improve our ability to maintain healthy and sustainable river environment.

2. Materials and Methods

2.1. Sampling Sites

This case study takes the first section of the Lijiang River near Guilin as an example (**Figure 1**). The Lijiang River and its tributaries Taohuajiang River, Xiaodong River, Nanxi River, Liangfengjiang River and Ningyuan River run through the urban area from north to south. There are peak clusters, peak forests and single peak formed by 300 - 600 m limestone on both sides and the middle of the basin. The location map is shown in **Figure 1**. With the acceleration of urbanization and the development of tourism along the Lijiang River, many pathogens, heavy metals, organic compounds, ammonia nitrogen and other pollutants have been discharged into the river [17] [18] [20] [21] [22]. An important factor in pathogens is the Taohuajiang River tributary which exceed all criteria even more than Lijiang River, with a four-year average of 810,000N/L, N is the number of pathogenic bacteria per Litre [19]. Because the Lijiang River supports the city of Guilin for its main commercial catch of fish, important local food, and an important fishery, the movement is particularly important to investigate the pathogen location. For example, differences in the presence of bacteria in different sites will support the selection of seaweed farming sites based on assessments of local sources that may affect bacterial in the rivers.

Table 1 uses various time series error measurements [23] to analyze water quality with fecal coliforms and *E. coli* as sanitary purity of water. According to the water quality monitoring, the pathogenic bacteria of Lijiang River is good, but the water quality change since the water quality of Taohuajiang River flow to Lijiang River is poor, which is affected by domestic sewage discharge and surface rescue.

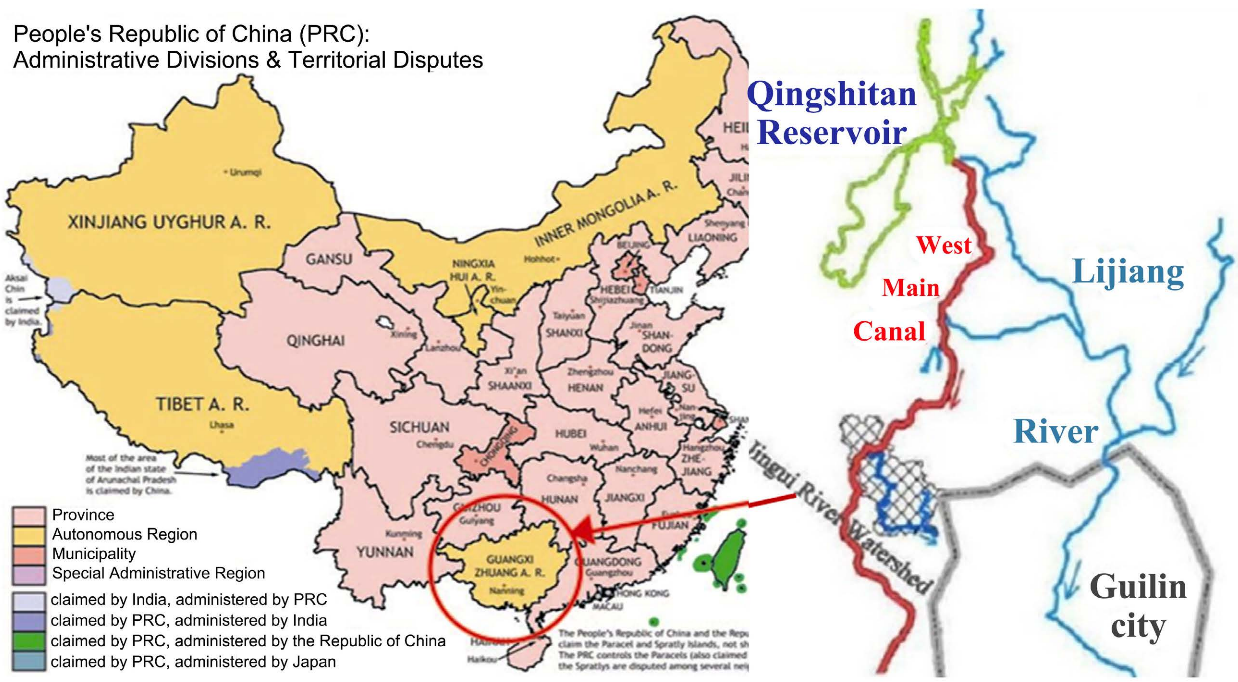

Figure 1. Map of the sampling site.

Table 1. Pathogens (fecal coliforms and *E. coli*) in Lijiang and Taohuajiang Rivers (Average level from 2005 to 2015), unit: MPN per 100 ml.

Variables	April-June		July-September		October-March	
	Fecal Coliforms	*E. coli*	Fecal Coliforms	*E.coli*	Fecal Coliforms	*E. coli*
Mean Error (mg/l)	−109.72	85.34	−148.85	−26.83	48.27	−18.04
Absolute Error (mg/l)	228.38	144.59	222.97	32.46	150.25	64.79
Relative Error (%)	74.27	251.73	79.31	87.20	109.29	43.91
RMS Error (mg/l)	536.76	501.43	740.74	104.91	461.85	144.79
Relative RMS Error (%)	13.78	20.89	16.12	14.78	23.13	7.24
Sample size	18	117	36	45	46	66

2.2. Model and Equations

In a liquid and solid phases, important transport and fate processes of pathogens include advection, dispersion, reversible and irreversible retention, and decay in liquid and solid phases. As the release of pathogenic bacteria under steady-state conditions is a slow and diffusion-controlled process, the release rate coefficient is usually several orders of magnitude lower than the retention rate coefficient [24], so in this study, the forward dispersive transport and the retention release of first-order microorganisms are mainly considered. Assuming that there is no suspended matter in the sediments (due to the lack of sediment information in Lijiang River), the first-order decay equation can be used to simulate the bacterial distribution in the downstream of the river, and the solution is as follows:

$$N = N_0 \exp\left(-K_B * t\right) \quad (1)$$

where, N is the number of pathogenic bacteria per Litre; N_0 is the number of pathogens at the upstream point; K_B is the decay rate at time T. According to the Thomann's Surface Water Modeling and Control, decay rates of pathogens, including *E. coli*, are generally in the 0.8 - 2.0 day^{-1} range. The Model Maker software was used to calculate the distribution of pathogenic bacteria in Lijiang River. Assuming a steady-state gushing river with a constant flow rate and direct mixing, the sewage treatment plant is located within the limits of Guilin city, 20 kilometers away from Taohuajiang River tributary. Figure 2 shows the conceptual model of the river and its parameters.

2.3. Sampling and Model Results

The bacterial model includes fecal coliforms and *E. coli* in 2005-2015, as shown in Table 1. To further verify the model, Figure 3 shows the comparison between the observed data of pathogenic bacteria and the model results in four seasons in 2011. It found that the model was able to capture major trends, including seasonal fluctuations in pathogens. Specifically, in cold weather, when the water temperature is low, the simulated pathogen shows a relatively stable state, and at a relatively high temperature, the pathogen shows a lower level. In Figure 3, the

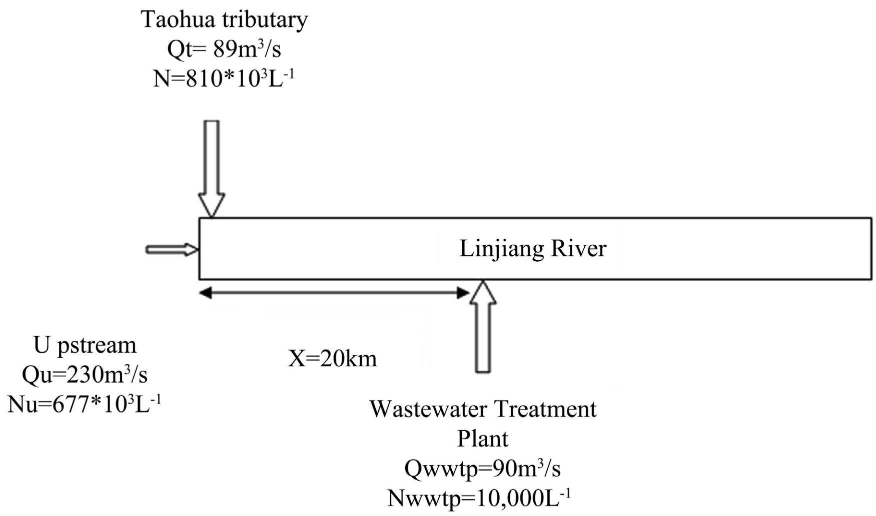

Figure 2. Pathogen concept model of Lijiang River in model maker.

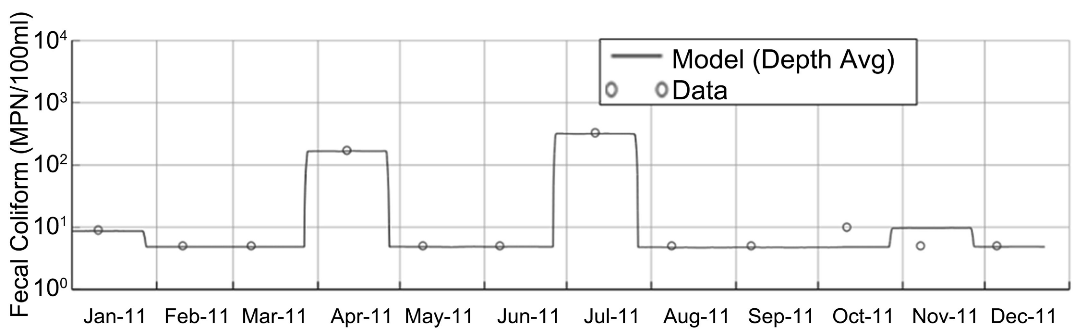

Figure 3. Comparison between observed pathogen data and model results under four seasons of the year of 2011.

difference between the estimated model and measured values is due to a stream with more fecal coliform loading sources than monitored for non-point fecal coliform loading sources [25].

3. Effect Analysts

3.1. The Effect of Velocity

In general, the water velocity (V) controls the convective transport and residence time of pathogens in the porous medium. Therefore, three different speeds (0.4 m/s, 0.8 m/s, 1.6 m/s) are included to simulate attenuation under those different velocity conditions. These three different speeds represent three different scenarios, with low velocity representing the best case of pathogen decay and maximum velocity representing the worst case. In the best case, when the equivalent point is reached, more decay will occur; In the worst case, higher peak concentrations and greater receding distance are associated with faster velocity but less retention, while the opposite trend is associated with slower velocity. In **Figure 4(a)**, in the low velocity with the best-case scenario, the decay curves show a drop in pathogen concentration at the wastewater plant effluent point at 20 km.

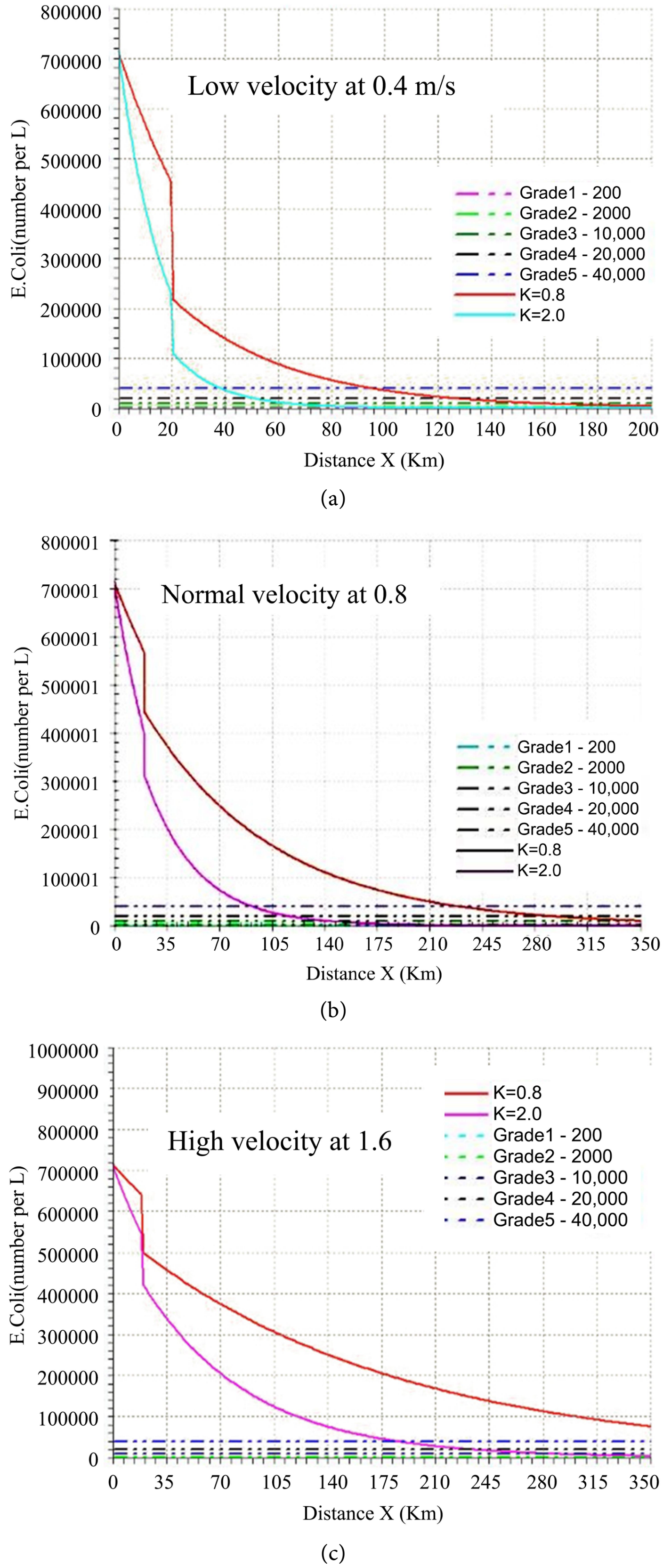

Figure 4. Pathogen Effect of velocity to the Lijiang River. (a) Low velocity at 0.4 m/s; (b) Normal velocity at 0.8 m/s; (c) High velocity at 1.6 m/s.

This is significant because it brings the water to a range within the lowest pathogen grade—Grade V, for agricultural and general landscape uses. Although the exact distribution of agriculture in Guilin and surrounding areas was not found, this information is significant if the city has agriculture just downstream of its boundary. In **Figure 4(b)**, despite being brought closer to the Grade V standard, the water still does not reach that quality level by the time it exits Guilin at 30 km. In the case of a high decay coefficient, Grade V quality is reached at around 40 km from the tributary – 10 km outside of the city. On this same curve, 50, 60, 90, and 130 Km are the crossing points for Grades IV, III, II, and I respectively. This means that, not considering additional minor tributaries along the path down the Lijiang, Yangshuo (75 Km) receives Grade III quality water and Pingle (100 Km) receives Grade II quality water. These levels are suitable as sources for drinking water according to Chinese National standards. By the time the Lijiang intersects Guijiang, at the city of Wuzhou, in the low decay rate situation, water pathogen quality will still not have reached Grade I. In **Figure 4(c)**, at the highest velocity, with the higher decay rate of K_b = 2.0, landscape usage standards (Grade V) are reached by 200 km, while industrial use standards (Grade IV) are reached by 230 km. Drinking water source standards (Grade III) are reached by 280 km. At the same velocity, but with the lowest decay rate of K_b = 0.8, Grade V quality for pathogens is not reached by the time Wuzhou is reached, at which point the Lijiang River will soon merge with the Guijiang. In such conditions, pathogen pollution from Guilin is not only severely detrimental to the city and its surroundings, but even the city all the way at the end of the Lijiang. Given that such velocities are not uncommon during rain storms this should be seen as an existing problem in Lijiang River. Mere physical contact with these waters can lead to human and animal infections.

It can be pointed out that the higher the river's flow rate, the slower the rate of decay. That is, the pathogens had traveled further before reaching the same numbers they would at slower velocities. A decrease in the pathogen level at the wastewater input point represents dilution due to the relatively high flow rate of effluent. It can be seen from **Figure 4** that, even with a high decay rate, the pathogen pollution level running through Lijiang city will remain lower than level V. This level of pollution is not even sufficient for landscape purposes. It poses a high risk to animal health. Given that this is a best-case scenario, we can expect higher velocity rates to produce longer distances before reaching the level of pathogens suitable for any water use.

3.2. The Effect of Temperature

Temperature is an important parameter that affects the reaction rate and solubility of gases and solids in rivers. **Figure 5** shows the annual mean seasonal variation of river pathogens with the distance from the disposal point. The variation of temperature will have a significant influence on the quality balance of pathogenic bacteria in Lijiang River. **Figure 5** is a good illustration of the significant increase in pathogen concentration due to increased water temperature. It

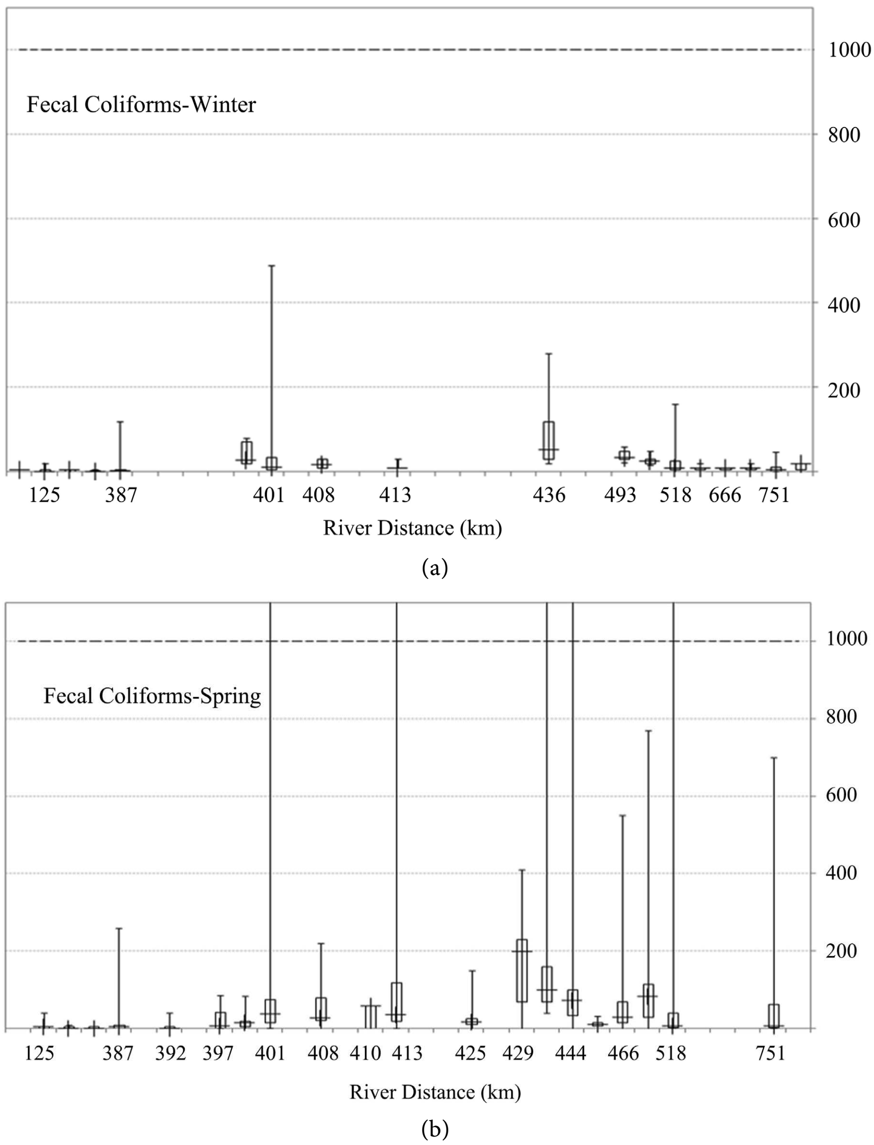

Figure 5. Pathogen (Fecal Coliforms) effect of temperature to the Lijiang River. (a) Winter; (b) Spring.

can also be seen from **Figure 5** that the increase of water temperature in spring leads to a sharp increase in the concentration of pathogenic bacteria, and when the water temperature is low in winter, the simulated pathogenic bacteria are relatively stable, which is lower than the concentration of pathogenic bacteria at high temperature.

4. Discussion and Conclusion

According to the study of pathogenic bacteria in Lijiang River and its tributaries, Taojiang River and Xiaodong River, the main monitoring indexes are coliform bacteria (fecal coliforms and *E. coli*). Using numerical models to enhance existing pathogen surveillance, we identify pathogen processes that affect microbial fate and distribution. Discuss the influencing factors such as flow and temperature, it can be noted that the higher the flow of the river, the slower the rate of decay, and the higher the level of pathogen contamination. The concentration of pathogens increases significantly with the increase of water temperature, among which, the concentration in pathogenic bacteria is very high in spring, and it is relatively stable in winter.

In this study, it is also important to identify the possible pathogen sources of Lijiang River. In large, urbanized watersheds such as the Lijiang River, the release of treated wastewater is the main source of microorganisms, while the input of fecal bacteria from non-point sources (such as surface runoff and soil leaching) is another major source. These diffused non-human sources also have a significant impact on the microbial quality of small local water sources and rivers [19] [26]. A comprehensive analysis may find that non-point sources (such as agriculture) or other cities along the Lijiang River contribute more to point sources. Since the pathogen analysis does not consider additional pathogens from other sources along Lijiang River after Guilin, it can only be considered as a rough estimate of the distribution or contribution of pathogens from major sources before Guilin. An increase in bacterial contamination has also been associated with recreation and tourism in some areas [27]. By disinfecting wastewater, the reduction in fecal bacteria input to wastewater can be reduced to terrestrial sources (non-point sources) [28]. To reduce the discharge of pollutants to the point of contact (water storage), a range of control measures can be adopted to reduce the risk of pollutants passing through the discharge system. In addition, fishing is a cherished tradition in Lijiang River; it has been noted that the number of fishing boats in Lijiang River has decreased over the years due to the decline in the number of fish in the river. It is not impossible to attribute this decline in part to high levels of pathogenic bacteria in rivers.

In addition, if the soil conditions are not too loose and the soil contains a large amount of organic matter conducive to plant growth, the construction of wetlands along Lijiang's agricultural routes should be feasible. Guilin is dominated by red loam, so the concentration of sand, silt and clay is relatively uniform. Therefore, the soil should be suitable for wetland construction.

In this study, the most effective way to improve the pathogen conditions in Lijiang area would be to directly change the main source of the pathogen into rivers. The upper reaches of the Lijiang and Taohuajiang Rivers are both important culprits because of their high concentration of contribution. Pathogen pollution in Lijiang River is a typical problem in drinking water due to its persistence in environment and resistance to conventional treatment techniques. Simply taking this analysis into account, pathogen levels are at excessive risk throughout the river, particularly during periods of high velocities and high temperature seasons, such as spring. Eliminating this problem could prevent unnecessary infections in humans and animals. While wastewater discharges are the most important point source input for fecal pollution in Lijiang River, non-point sources and diffuse inputs throughout the city place a relatively large load on the river and are more problematic to manage. The mass balance flux between the estimated and measured values of point source loading points is poor, indicating the presence of significant non-point sources. In the long run, agricultural runoff may be a major, controllable contributor to pathogens. The introduction of wetlands reduces the chance of pathogens entering rivers from cultivated land. They have been shown to be effective in reducing the number of pathogens introduced into surface water.

Data Availability Statement

All relevant data and code generated by the authors or analyzed during the study are within the paper and its supporting information file.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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