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Analyzing Urban and Rural Water Pollution Impacts with an Integrated Ecological Governance Model Approach

Yanjie He [1*], Xiujun Sun [1], Nan Shan [1], Beibei Qie [2], Yiming Wang [3]

[1] *School of New Materials and Chemical Engineering, Tangshan University, Tangshan 063000, China.*

[2] *School of Sports Medicine and Health, Chengdu Sport University, Chengdu 610041, China.*

[3] *Tangshan Laixin Technology Co., Ltd.Tangshan 063000, China.*

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Abstract

From the perspective of aquatic ecology, there are problems of insufficient analysis and poor governance effect on the impact and ecological governance of urban and rural water pollution. Therefore, to achieve a good water cycle, it is of great practical significance to analyze the impact of urban and rural water pollution from the perspective of aquatic ecology and study the ecological governance model. Taking a certain research area as an example, an integrated ecological governance model under the perspective of aquatic ecology is designed, including source control, pollution interception, and restoration. The impact of urban and rural water pollution on soil environment, groundwater environment, and agricultural environment is analyzed, and the change of water pollution concentration before and after application is studied. The research results show that in the soil environment of the research area, most areas are lightly polluted, two other areas (Area 3, Area 4) are heavily polluted, one area (Area 7) is moderately polluted, and one area (Area 11) is unpolluted; in terms of groundwater environment, the degree of groundwater pollution in Area 1 and Area 2 is the highest, followed by Area 3 and Area 4, then Area 7 is moderately polluted, and other areas are lightly polluted or unpolluted; in terms of agricultural environment, as the pollution degree of irrigation water source increases, the emergence rate, yield, and dry matter content of crops all show a decreasing trend, indicating that the more serious the water pollution, the more serious the impact on the agricultural environment; after applying the research method, the highest water pollution concentration has been reduced by 0.8 mg/L, and the overall data is below 1.0 mg/L, the water pollution concentration has been reduced. Through this research, it is expected to achieve in-depth ecological governance and protect the aquatic environment.

Keywords: Water Ecological Environment Perspective; Urban and Rural Water Pollution; Impact Analysis; Source Control; Pollution Interception and Repair; Ecological Governance Model.

1. Introduction

Most human activities are predicated on the consumption of material resources, which are often obtained from natural resources and transformed to meet daily production and living needs. Among various natural resources, water resources are essential for meeting human needs, supporting agricultural irrigation, and facilitating industrial production [1]. However, human activities generate various forms of water pollution, including domestic, industrial, and agricultural pollutants [2-5]. This pollution, if untreated and discharged into natural ecosystems, can severely compromise water

* Corresponding author: hyjtsxy@163.com; heyanjie@tsc.edu.cn

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quality and lead to adverse ecological effects, including gastrointestinal diseases in humans [6-8]. Consequently, effective governance of water pollution is crucial to safeguarding both environmental health and public safety [9].

Numerous scholars have investigated the multifaceted aspects of water pollution management. For instance, Han Dongmei et al. investigated the characteristics of organic pollutants in their research, analyzed the characteristics of water pollution caused by these pollutants and the current situation of pollution, proposed three detection technologies for this pollution, and finally proposed three sewage treatment technologies [10]. Similarly, Chen Guolei et al. examined the pollution characteristics of water bodies along the city-village line in their research and formulated a source control and pollution interception strategy based on these characteristics. This strategy involved analyzing four sewage collection methods and proposing sewage treatment methods before conducting application cases and evaluating the effectiveness of the strategy [11]. Chen Si et al. conducted a study in a specific area of Chongqing, collecting groundwater type and sampling point distribution data as well as natural environmental elements, human activity elements, and water quality monitoring data from various sources. They employed an APCS-MLR model for source analysis and a geographic detector to identify influencing factors [12]. Chen and Ding emphasized the necessity for improved governance frameworks to address heavy metal water pollution, outlining prominent governance models such as state-centric and market governance, ultimately aiming to provide recommendation strategies for effective remediation [13]. Complementarily, Bi et al. explored the intricate connections between urbanization and water-related ecosystem services, revealing that a coordinated growth of these systems is pivotal for managing environmental challenges in regions like the Yangtze River Economic Belt [14]. Their findings suggest that varying governance and urban development strategies must be tailored to enhance ecosystem services, thereby contributing to holistic environmental management. In specific regions, changes in water resource allocation and industrial development have been shown to influence pollution levels significantly. For example, Genova and Wei developed a socio-hydrological model that demonstrated how adaptive management of water resources, as seen in the Maipo River basin, could facilitate better allocation practices while also influencing environmental regulations to mitigate ecological degradation [15]. This underscores the importance of dynamic governance that considers socio-economic impacts alongside ecological outcomes.

Furthermore, in Hubei Province, He et al. identified pathways for reducing agricultural water pollution through a nuanced understanding of the spatial-temporal dynamics of agricultural grey water footprints and their relationship with agricultural GDP [16]. This differentiated management approach highlights the necessity of localized strategies to control agricultural contributions to water pollution, which is echoed by Xu & Chen, who similarly examined the coupling coordination between socio-economic development and water environments in Taihu Lake, advocating for integrated watershed management solutions [17]. Niu et al. addressed the implications of urban-rural integrated development on land-use transition, revealing that the connection between land management and environmental quality is complex and necessitates a carefully balanced approach at multiple scales [18]. By employing a multi-scale framework, they illustrate how different regions can benefit from tailored land-use strategies that foster integrated urban-rural development and improve water resource management.

Moreover, Zhang et al. proposed an integrated diagnostic framework for assessing water resource spatial equilibrium, linking ecological, economic, and social factors to better understand the distribution of water resources in China [19]. Their findings stress the critical need for efficient water governance by highlighting the disparities in water resource distribution compared to human activity concentrations, further accentuating the resilience challenges posed by climate variability. Kong et al.'s exploration of advanced industrial structures in Jiangsu Province provides additional evidence of how industrial development directly correlates with water pollution management. Their study demonstrated that an advanced industrial structure could alleviate regional water quality crises, and they emphasized the role of tailored policies to improve the adaptability of industrial sectors in managing water pollution effectively [20]. Similarly, Chen et al. developed a multi-objective optimization model to allocate agricultural soil and water resources more sustainably under fuzzy and stochastic uncertainties, thus balancing economic benefits, pollution control, and water use efficiency in their model [21]. This highlights the growing recognition of the need for integrated resource management frameworks that account for unpredictable variables in water governance. Additionally, the assessment of water use efficiency and its impact factors across China revealed significant spatial variations, indicating a pressing need for targeted strategies to enhance efficiency in less productive regions [22]. The geographical disparities in resource use further complicate integrated water management, underlining the importance of localized analyses in understanding and managing water-related issues. Finally, Chen et al. contributed to this critical discourse by linking ecosystem service flow to water-related ecological security patterns, thereby advancing methodological approaches for sustainable water management that include both ecological and human factors [23].

In summary, the cumulative insights from these studies underscore the imperative for comprehensive and systematic approaches to water governance that not only address pollution at multiple scales but also recognize the interconnectedness of socio-economic factors and ecological health. By integrating these diverse research findings, our study aims to enhance the efficacy of water pollution governance in urban and rural areas, improving overall water quality and protecting aquatic environments through better-informed decision-making and localized strategies. This integrated perspective aligns with ongoing global efforts to combat water pollution by emphasizing the need for collaborative governance models and innovative management techniques tailored to specific regional challenges.

2. Theory and Method

In view of the significant impact of urban and rural water pollution, effective ecological governance is crucial for achieving practical outcomes. Previous governance models have been relatively single-layered, leading to suboptimal results. To address this issue, an integrated ecological governance model combining source control, pollution interception, and restoration is proposed, as illustrated in Figure 1.

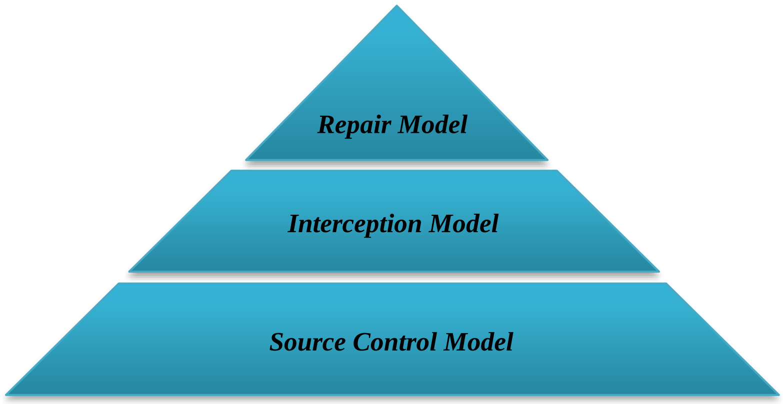

Figure 1. Schematic diagram of the integrated ecological governance model of source control, pollution interception, and restoration

2.1. Source Control Model

The source control model, as its name suggests, aims to control the source of pollution, which is the first layer of the ecological governance model. Without controlling the source of water pollution, pollution will persist, and subsequent measures will be mere symptomatic treatments incapable of achieving ecological governance. The source control model primarily consists of two steps. The first step involves building a sewage collection pipe network. The lack of regular sewage collection channels is a significant contributor to environmental pollution [24]. By establishing a network of sewage pipes, this issue can be addressed. For example, in densely populated urban areas and industrial zones, sewage pipes can be connected at sewage outlets and linked to municipal pipelines nearby [25]. In sparsely populated rural areas, fixed sewage collection points can be set up [26], allowing villagers to concentrate their waste disposal nearby. The second step involves building additional sewage treatment plants. While reducing water usage and sewage production can quickly achieve governance effects, this approach is not sustainable in the long term; increasing sewage treatment capacity and effectiveness is essential. After completing the above-mentioned sewage collection, the other end of the sewage collection pipe network is connected to the sewage treatment plant, where advanced equipment centrally purifies the sewage. The purified sewage can be directly discharged into the natural environment or used for other purposes, such as irrigation and industrial production.

However, the selection of treatment processes in wastewater treatment plants is crucial. Different types of wastewater require the use of different treatment methods. For example, for wastewater containing a high concentration of organic matter, biological treatment processes, such as the activated sludge method, can be employed. In the activated sludge method, aeration facilitates sufficient contact between microorganisms in the wastewater and organic matter, allowing the microorganisms to decompose the organic materials and thereby purifying the wastewater. For wastewater containing heavy metal ions, special treatment processes such as chemical precipitation or ion exchange methods are necessary. Chemical precipitation involves adding chemical agents to the wastewater, which leads to the formation of precipitates, effectively removing the heavy metal ions. The ion exchange method uses ion exchange resins to adsorb heavy metal ions from the wastewater, which can then be recovered by regenerating the resin. Throughout the wastewater treatment process, attention should be given to the recovery and utilization of resources. For instance, the organic matter in the wastewater can be subjected to anaerobic fermentation to produce biogas, which can be used as an energy source for the operation of the wastewater treatment plant, such as for electricity generation or heating. Additionally, the nutrients (such as nitrogen and phosphorus) in the treated wastewater can be recovered and converted into fertilizers for agricultural production. This approach not only reduces the costs associated with wastewater treatment but also promotes resource recycling, enhancing the sustainability of the entire ecological governance system.

2.2. Pollution Interception Model

The pollution interception model, as its name suggests, aims to intercept pollutants in the water. Despite the effectiveness of sewage source control in addressing water pollution, it cannot eliminate the problem; therefore, a pollution interception model is necessary to supplement this approach. The interception model consists of two layers: the first layer is the ecological concrete layer, which is distinct from traditional engineering concrete. This filtering and adsorption device features a special pore structure composed of graded aggregates and other materials. When sewage passes through this device, it can intercept some of the pollutants present in it. The composition of this device includes cementitious materials, coarse aggregates, admixtures, mixing water, mineral additives, and nutrients. The preparation process for constructing the first layer involves the following steps: Initially, a small amount of water is added to the coarse aggregate for pre-wetting. Next, cementitious materials are added and mixed and stirred for a while. Admixtures, mineral additives, and nutrients are then added and stirred until coated. The mixture is finally molded and dried to complete the construction of the first layer of the interception model. The second layer is the ecological isolation belt layer [27], comprising trees, shrubs, grassland, and other plants. These plants utilize their root system interception ability and decomposition ability to slow down water flow and intercept pollutants in the water.

As sewage flows through this ecological isolation belt layer, the flow speed slows down, allowing pollutants to be intercepted and even purified, thereby reducing surface runoff pollution into the river. When selecting plants for the ecological isolation belt layer, it is essential to optimize choices based on local climatic and soil conditions. In addition to commonly used trees, shrubs, and grasses, certain plants with specialized pollutant interception capabilities can also be introduced. For instance, some wetland plants exhibit a strong ability to absorb nutrients such as nitrogen and phosphorus; planting these at the edges of the ecological isolation belt can help effectively retain these nutrients from the wastewater. The arrangement of plants should consider the growth habits and spatial requirements of different species. Trees can provide shade, reducing moisture evaporation, while their deep root systems help stabilize the soil and prevent erosion. Shrubs can fill the gaps between trees, thereby increasing vegetation coverage. Grassland plants can cover the soil surface, slowing down rainwater runoff and increasing the retention time of wastewater within the ecological isolation belt, which enhances the pollutant interception effectiveness. By combining these two layers of interception, the concentration of pollutants in the water can be significantly reduced and water quality improved.

2.3. Restoration Model

Restoration, as the name suggests, aims to restore the water environment [28, 29]. While the source control and pollution interception models can quickly reduce pollutant concentrations, they cannot completely purify the water. Moreover, pollutants in the water damage the water environment, necessitating deeper restoration to achieve a good ecological cycle [30]. The ecological restoration model in this study is designed to address these concerns by establishing an artificial system that simulates the prevention and control functions of natural wetlands. This model consists of five components: a permeable matrix; aerobic bacteria (nitrogen-fixing bacteria, Bacillus subtilis) and anaerobic bacteria (urea-degrading bacteria, Pseudomonas aeruginosa, and Porphyromonas spp.); duckweed, reed, bitter grass, and other aquatic plants; tadpoles, snails, waterfowl, and other aquatic animals; and a water body. In ecological floating islands, the permeable substrate provides a habitat for both aerobic and anaerobic bacteria. The pore structure and chemical properties of the substrate can influence microbial growth and metabolic activities. For example, a substrate with a higher porosity and abundant surface functional groups can offer more attachment sites for microorganisms, promoting their proliferation. Aerobic and anaerobic bacteria play distinct roles within the ecological floating island. Aerobic bacteria can rapidly decompose organic matter in wastewater under aerobic conditions, converting it into carbon dioxide and water.

In contrast, anaerobic bacteria decompose organic matter under anoxic or anaerobic conditions, producing gases such as methane. There exists a synergistic relationship between the two: some intermediate products generated by the aerobic bacteria can be further decomposed by anaerobic bacteria, thus enhancing the overall efficiency of organic matter removal from wastewater within the ecosystem. Floating plants such as duckweed can cover the water surface, reducing direct sunlight exposure and lowering water temperature, which helps inhibit algal growth. The root systems of emergent and submerged plants, such as reeds and sedges, can absorb nutrients from the wastewater while also providing habitat for aquatic animals. Tadpoles feed on algae and aquatic plants, while their excrement provides nutrients for these plants. Snails scrape algae and microorganisms off the surfaces of aquatic plants, promoting their growth. Waterfowl forage and roost within the ecological floating island; their droppings supply nutrients to the microbes and plants in the island, and their movements help mix the water, increasing the dissolved oxygen content. Thus, the polluted water is introduced into the ecological floating island, where the synergistic interactions among the substrate, microorganisms, and aquatic plants and animals facilitate purification over time. Eventually, the treated water from the ecological floating island can be discharged into surface rivers, allowing for either wastewater replacement or secondary utilization [31].

The integrated ecological governance model of source control, pollutant interception, and ecosystem restoration developed in this study follows a hierarchical progression. The source control phase focuses on reducing the generation and discharge of wastewater, the pollutant interception phase effectively lowers the concentration of contaminants in the water, and the restoration phase involves deep purification of the water body and recovery of the aquatic ecological environment. Based on source control and culminating in restoration, this multi-layered approach effectively addresses water pollution, purifies water quality, and ensures safe water use in urban and rural areas. The implementation flowchart for the urban-rural water pollution ecological governance model is illustrated in Figure 2.

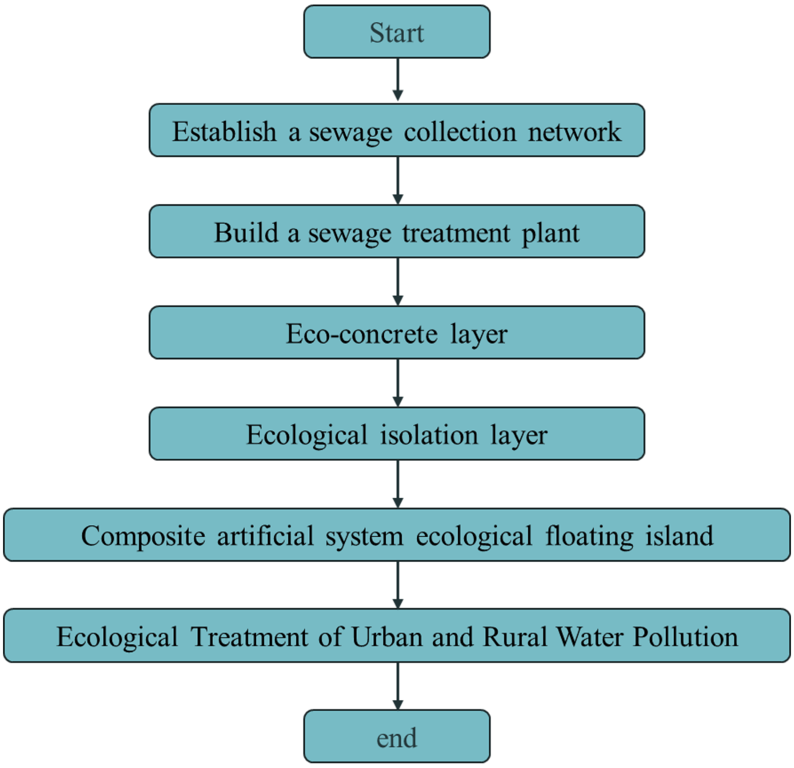

Figure 2. Flow chart of ecological treatment of urban and rural water pollution

3. Results and Analysis

Urban and rural water systems are the primary sources of urban water resources, playing crucial roles in climate regulation, flood control and drainage, and maintaining ecological balance. Once water resources become polluted, the functions of water resources will gradually deteriorate. In light of this situation, it is essential to analyze the impact of urban and rural water pollution in order to achieve effective governance of these resources. This chapter examines the impact and ecological governance of urban and rural water pollution through the previously described model. Specifically, it presents the effects of water pollution on various aspects and provides tables or graphs of pollution index data for verification purposes. Subsequently, it identifies the source of pollution by analyzing the water pollution data.

3.1. Overview of the Research Area

This section presents an analysis of the impact of urban and rural water pollution in the Guangxi Zhuang Autonomous Region, as illustrated in Figure 3.

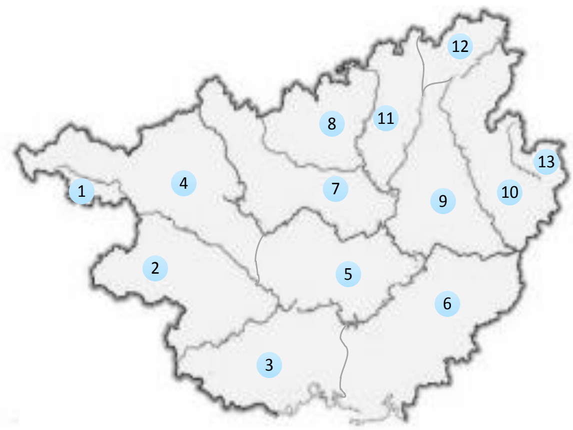

Figure 3. Schematic diagram of the study area

The study area features a well-developed water system, with rivers and tributaries almost ubiquitous throughout the region, providing crucial water resources for local residents' drinking needs, agricultural irrigation, and industrial production. In the plains, extensive irrigated farmland has been established, with crops such as rice and sugarcane relying on these water resources for growth. For instance, in the Central Guangxi Plain, a network of irrigation channels directs river water into the fields, ensuring that crop growth requirements are met. Some industrial cities in Guangxi, such as Liuzhou, which focuses on automotive manufacturing, and Nanning, which specializes in food processing and electronic information industries, require substantial water resources for cooling, cleaning, and other processes involved in production. However, with population growth and economic development, certain areas face increasing pressure regarding the protection of drinking water sources. For example, sections of rivers located near urban or industrial zones may be at risk of contamination. To effectively address pollution, a case study in Guangxi Zhuang Autonomous Region has established 13 monitoring points for long-term observation, analyzing the impact of urban-rural water pollution within the study area. The pollutants measured primarily included biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and heavy metals (such as cadmium, lead, and mercury). To ensure comprehensive monitoring, sampling was conducted bi-weekly to capture temporal variations in water quality influenced by factors such as rainfall, industrial discharge, and agricultural runoff. Upon collection, water samples were transported to a laboratory equipped for analysis, following strict chain-of-custody protocols to avoid contamination. The measurements were conducted using standardized methods in accordance with the protocols outlined by the American Public Health Association (APHA, Standard Methods for the Examination of Water and Wastewater) to guarantee the accuracy and reliability of our results. Additionally, we utilized spectral photometry for measuring BOD and COD, ion chromatography for assessing TN and TP, and atomic absorption spectroscopy for detecting heavy metals. Each sampling point was monitored consistently over a six-month period, allowing us to assess both immediate and cumulative effects of water pollution within the study area. This comprehensive monitoring strategy provided a better understanding of how the concentrations of pollutants changed over time in response to the implementation of our integrated ecological governance model, ultimately leading to the observed reductions in water pollution concentrations following our interventions.

3.2. Impact of Urban and Rural Water Pollution on Soil Environment

The soil environment is one of the primary areas affected by urban and rural water pollution through ecological circulation. Following the discharge of domestic sewage into the natural environment, pollutants can penetrate the soil. Some contaminants are degraded by microorganisms in the soil, while others persist in the soil. In comparison, the impact of industrial wastewater on soil pollution is significantly more severe due to the greater diversity of pollutants and their higher concentrations, making it more challenging to degrade them. Consequently, pollutants tend to accumulate in the soil, leading to more significant pollution. To assess the degree of soil pollution, we tested pollutants at 13 monitoring points and calculated the comprehensive pollution index using the Mero method. The results are presented in Figure 4.

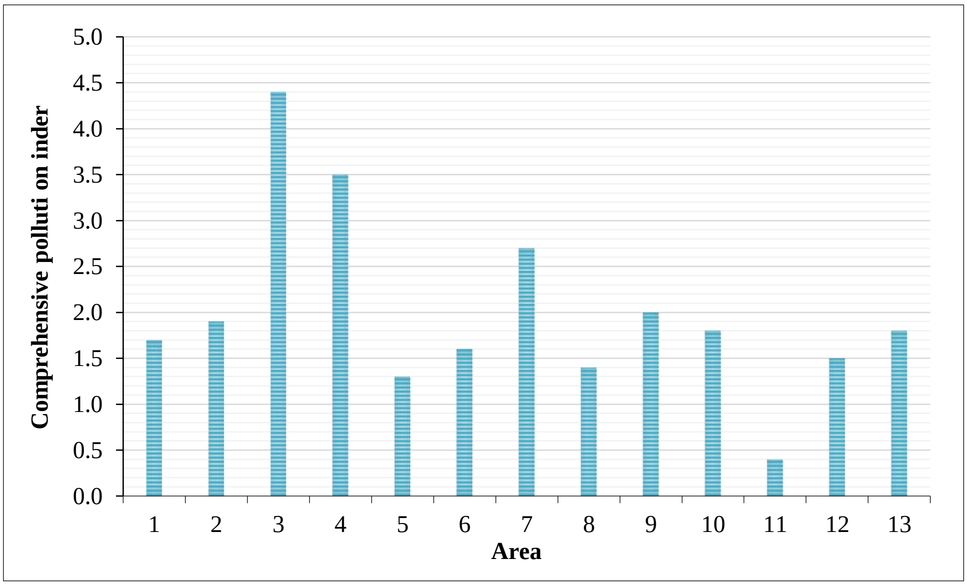

Figure. 4 Impact of urban and rural water pollution on soil environment

From Figure 4, it can be observed that most areas of the study region (Areas 1-2, Areas 5-6, Areas 8-10, Areas 12-13) are classified as lightly polluted, while the remaining two areas (Areas 3 and 4) are identified as heavily polluted. One area (Area 7) is classified as moderately polluted, and one area (Area 11) is considered unpolluted. This discrepancy can be attributed to the concentration of industrial activities primarily in Areas 3 and 4. Area 7 is characterized by the presence of livestock farms, where the wastewater generated from these operations is discharged into the environment without treatment. Area 11 consists of steep mountainous terrain, which has not been subjected to excessive human development. As a result, the area maintains a well-preserved ecological environment, with water sources remaining unpolluted, and consequently, the soil environment also remains uncontaminated.

3.3. Impact of Urban And Rural Water Pollution On The Groundwater Environment

The secondary impact of urban and rural water pollution is groundwater pollution. Various activities undertaken by urban and rural residents generate sewage. For example, domestic sewage contains a large amount of organic matter. When this organic matter enters the groundwater environment, it can result in the generation of odorous substances, bacteria, and pathogens. Meanwhile, the pollutants present in industrial wastewater are more diverse and difficult to degrade, which can fundamentally alter the pH value of the water body and cause significant harm to aquatic organisms. As this sewage is discharged into the environment, it gradually penetrates the groundwater system through water circulation, leading to pollution. According to the pollution pathways, it manifests in three forms:

- ***Intermittent Infiltration Pollution:*** This type of pollution occurs when a pollutant source penetrates the aquifer after passing through the soil layer, resulting in groundwater contamination. A characteristic of this pollution is its slow rate and intermittent process.
- ***Continuous Infiltration Pollution:*** In this case, the pollution source continuously produces pollutants, which penetrate the groundwater source after traversing the soil.
- ***Runoff Pollution:*** This form of pollution is characterized by pollutants that directly enter the groundwater without passing through the soil layer. The source of this pollution may be the groundwater environment itself, or it may arise from the direct discharge of wastewater into the aquifer. This type of pollution is particularly severe.

Groundwater samples were collected from 13 monitoring points in the research area, and the permanganate index acidity method was utilized to detect the permanganate index. The degree of groundwater pollution was classified based on these measurements. The results are presented in Figure 5.

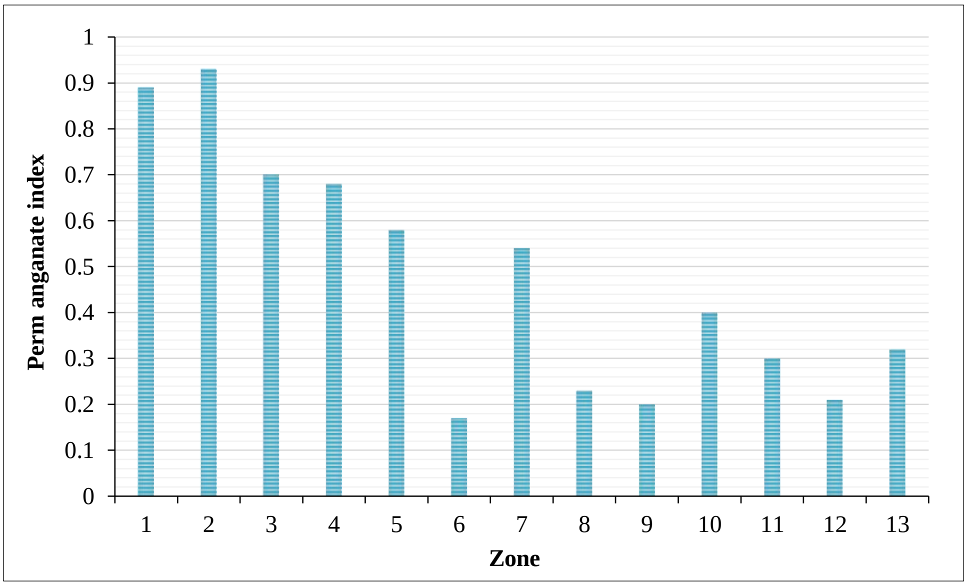

Figure 5. Impact of urban and rural water pollution on the groundwater environment

From Figure 5, it is evident that the degree of groundwater pollution in Areas 1 and 2 is the highest. This can be attributed to these areas being rural gathering zones where sewage discharge is rarely treated regularly. Additionally, rivers that pass through this area contribute to runoff pollution, allowing pollutants to directly enter the groundwater layer. The next highest levels of pollution are found in Areas 3, 4, and 5, where industrial wastewater continuously infiltrates the soil layer and subsequently reaches the underground aquifers, resulting in significant pollution. Following these, Area 7 is classified as experiencing moderate pollution, with sources of contamination intermittently seeping into the groundwater layers, leading to groundwater pollution. Finally, the remaining areas (Areas 6, 8-13) fall within the categories of lightly polluted and unpolluted. These areas are primarily urban and have a higher number of wastewater treatment plants. Even in cases of pollution, the treatment facilities are capable of purifying the wastewater, resulting in minimal groundwater pollution in these regions.

3.4. Impact of Urban and Rural Water Pollution on Agricultural Environment

In addition to being used for residents' drinking and industrial production, water resources are also utilized for agricultural irrigation. Urban and rural water pollution contains various harmful substances; when polluted water is used to irrigate crops, it adversely affects the agricultural planting environment. The impact primarily manifests in two aspects:

- ***Reduction in Crop Yield:*** Various pollutants in contaminated water can damage the growth of crops to a certain extent, leading to reduced yields. For instance, when the chemical oxygen demand (COD) in irrigation water is excessive, it severely hinders the metabolic activities of crops, impeding root growth and potentially causing root rot, which can result in plant death. Similarly, when the nitrogen content in sewage is too high, it might weaken the vitality of crops, leading to issues such as elongation, lodging, and increased susceptibility to diseases, ultimately resulting in plant mortality. Additionally, high concentrations of heavy metals in sewage can directly cause crops to exhibit symptoms of chlorosis, whereby severely affected plants may die outright.
- ***Decline in Crop Quality:*** High levels of pollution in irrigation water can lead to a decline in crop quality, even if it does not cause immediate crop death. Pollutants hinder the absorption of nutrients by plants, resulting in insufficient accumulation of essential substances, deterioration in product taste, and a decrease in crop quality.

To illustrate these impacts, consider the three agricultural planting areas in the research region—Area 1, Area 2, and Area 6. We tested three indicators: crop emergence rate, yield, and dry matter content. The test results are shown in Figures 6 and 7, as well as in Table 1.

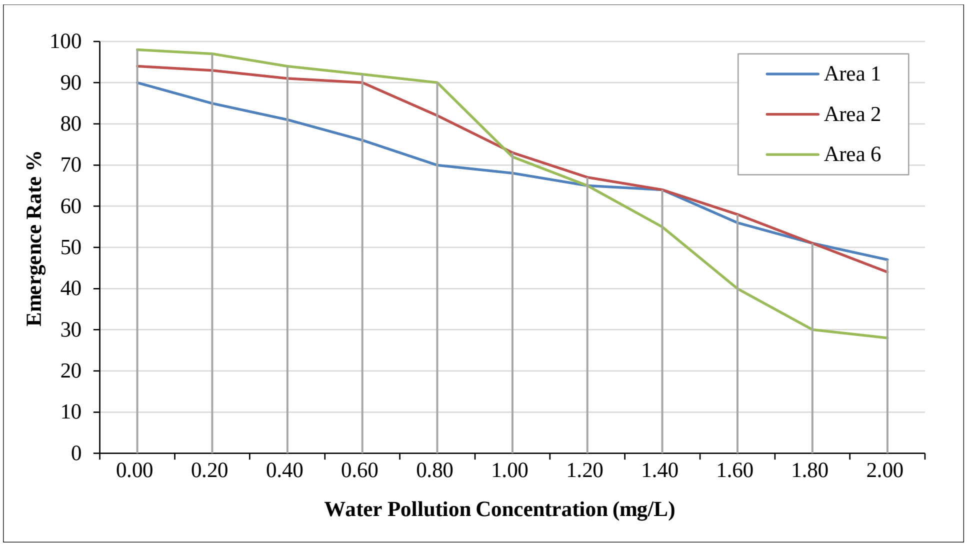

Figure 6. Comparison of crop emergence rate

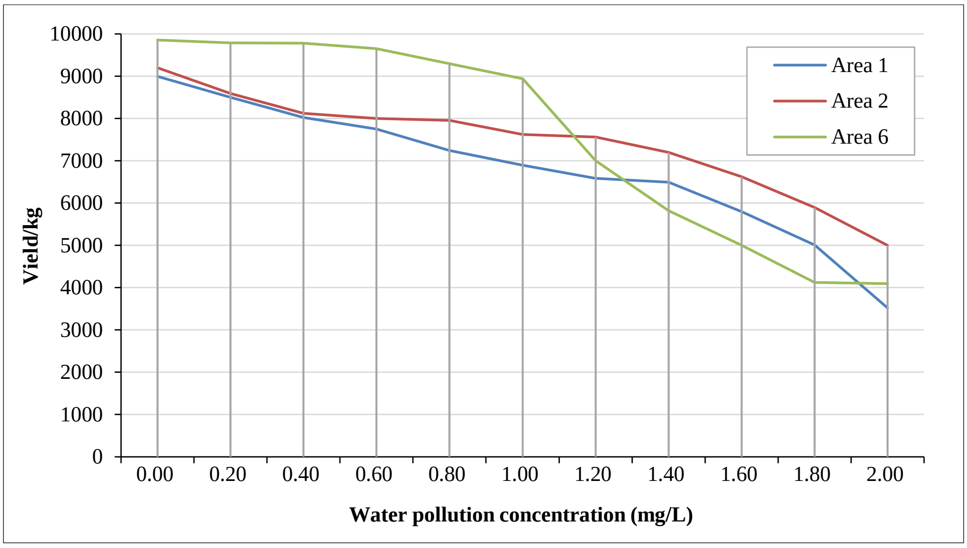

Figure 7. Comparison of crop yield

From Figures 6 and 7, as well as Table 1, it can be observed that with the increasing levels of irrigation water pollution, the emergence rate, yield, and dry matter content of crops demonstrate a decreasing trend. Specifically, in Area 3, the emergence rate and yield of crops are higher than those in Areas 1 and 2. However, when the pollution level of the irrigation water reaches approximately 1.00 mg/L, a rapid decline is observed. Conversely, the emergence rate and yield in Areas 1 and 2 exhibit a stable downward trend as the pollution levels of the irrigation water increase, with Area 1 showing lower emergence rates and yields than Area 2. This indicates that stricter control of irrigation water quality is needed in Area 3. Regarding the dry matter content of crops, Area 1 consistently shows lower dry matter content compared to Areas 2 and 3. This collectively highlights that more severe water pollution has a greater detrimental impact on the agricultural environment. In light of these findings, alternative agricultural practices can be explored to mitigate the effects of irrigation water pollution, thereby reducing its impact on agriculture. For instance, drip irrigation is a precise method that delivers water directly to the soil near the plant roots. Compared to traditional flooding irrigation, drip irrigation significantly reduces water usage and consequently limits the dispersion of pollutants from irrigation water in the soil. Micro-spray irrigation systems utilize nozzles to spray tiny droplets of water onto crops. This method allows for precise control based on the water requirements of the crops, preventing over-irrigation and ensuring uniform moisture distribution around the plants, which supports crop growth and enhances the crops' tolerance to pollutants. Additionally, constructing rainwater collection facilities, such as collection ponds or cisterns near farmland or within farms, can be highly beneficial. During the rainy season, rainwater can be collected and, after simple filtration and sedimentation processes, can be used for irrigation. This rainwater is relatively pure and free of potential contaminants found in polluted irrigation water, such as heavy metals from industrial wastewater. Moreover, rainwater collection and reuse can reduce reliance on external irrigation water sources, thereby decreasing the use of contaminated irrigation water.

Table 1. Comparison of dry matter content of crops

Water Pollution Concentration (mg/L)	Area 1	Area 2	Area 6
0.2	1.522	2.241	1.875
0.4	1.320	2.147	1.721
0.6	1.140	2.033	1.621
0.8	1.122	1.872	1.521
1.0	1.052	1.714	1.321
1.2	1.011	1.520	1.201
1.4	0.822	1.248	1.101
1.6	0.641	1.025	0.925
1.8	0.524	0.924	0.754
2.0	0.241	0.754	0.528

3.5. Ecological Governance Effect

After completing the above analysis, a comparison of the changes in water pollution concentrations before and after the application of the methods discussed in this paper will be conducted to assess whether these methods can contribute to ecological governance, reducing water pollution concentrations, and improving the water ecological environment. The implementation and monitoring of source control, pollution interception, and remediation factors in the study area are described as follows: For newly developed urban areas, wastewater discharge outlets should be directly connected to wastewater collection pipes according to modern urban planning standards, ensuring that design parameters such as pipe diameter and slope meet the requirements for wastewater flow. These collection pipes should then be connected nearby to municipal pipelines to form a complete wastewater collection network. For older urban areas, where infrastructure may be aging, it will be necessary to undertake pipeline renovation projects. This may involve inspecting existing drainage systems to identify points of wastewater leakage and drainage outlets that are not connected to the sewer network, gradually integrating them into a new wastewater collection system. In sparsely populated rural areas, such as some mountainous villages in Guangxi, wastewater collection points should be strategically established based on the distribution of villages and topographical features. For example, several neighboring villages can be grouped together, and a wastewater collection point can be set up in a relatively central and low-lying location. Additionally, supporting infrastructure such as small wastewater pipes or dedicated access roads for wastewater transport vehicles should be constructed to facilitate villagers in discharging wastewater at the collection points.

Within the study area, the construction scale of wastewater treatment plants should be reasonably planned based on factors such as population and industrial scale. For instance, in an industrial concentration area in Liuzhou, where large amounts of industrial wastewater are generated, a large wastewater treatment plant will be necessary. Following the aforementioned source control measures, pollution interception can be implemented. Ecological concrete layers should be established in areas prone to pollution, such as around rivers, lakes, and urban stormwater discharge outlets. Appropriate coarse aggregates and binding materials should be selected for the preparation of ecological concrete based on the availability of local raw materials. Subsequently, suitable plant species should be selected for ecological buffer zones based on the climate and soil conditions of different regions. In the subtropical humid areas of southern Guangxi, tree species such as banyan and hibiscus can be chosen, along with shrubs like oleander and ixora, as well as ground-cover plants such as dogtooth grass and carpet grass.

In the subtropical monsoon climate of northern Guangxi, tree species like camphor and ginkgo can be selected, along with shrubs like rhododendron and camellia, and grass plants like ryegrass and Kentucky bluegrass. In terms of vegetation arrangement, planting should follow a hierarchical structure of trees, shrubs, and grasses. Finally, the scale and layout of ecological floating islands should be determined based on the area and pollution level of the water body, with adjustments made to the species and quantities of microorganisms, plants, and animals within the floating islands in response to changes in water pollution levels. For example, if a significant proliferation of algae is observed, the number of floating plants such as water ferns can be increased to inhibit algae growth. Based on the above implementation, and according to the analysis results from sections 3.2 to 3.3, Areas 1, 2, and 3 are identified as experiencing severe pollution. Therefore, during the testing process, these areas will be selected for analysis, with an additional sampling point added at the outflow of the ecological floating islands in each section—two sampling points per research area. Since the removal of certain pollutants is a relatively slow process and the growth of plants and succession of microbial communities in the ecological floating islands also takes time, long-term sampling will provide a better reflection of the impacts of these long-term changes on water purification effectiveness. Thus, after a one-week application period, water samples will be collected to analyze changes in water pollution concentrations and evaluate the purification effects of the ecological floating islands. The experimental results are presented in Table 2.

Table 2. Changes in water pollution concentration before and after the application of the method

Area		Water Pollution Concentration (mg/L)		
		Before Application	After Application	Zhang et al. [19] Method
1	1	1.4	0.9	1.1
	2	1.5	0.9	1.0
2	1	1.6	1.0	0.9
	2	1.7	0.9	1.0
3	1	1.2	0.7	0.8
	2	1.1	0.6	0.8

According to the data in Table 2, it can be observed that the water pollution concentrations after the application of both the proposed research methods and the methods outlined in Zhang et al. [19] are lower than those recorded before the application. Among these, the proposed method achieved the greatest reduction in water pollution concentration in Area 2, with a maximum decrease of 0.8 mg/L. Other areas also experienced reductions in water pollution concentrations, although these were approximately 0.5 mg/L. Importantly, the water pollution concentrations following the application of the proposed methods were all below 1.0 mg/L, indicating an overall decrease in values. Additionally, the application of the methods from Zhang et al. [19] also resulted in a reduction in water pollution concentrations, with the highest decreases occurring in Areas 1 and 2, where the maximum reduction was 0.7 mg/L. However, these reductions are still lower than those achieved using the proposed methods. This indicates that the research methods not only effectively analyze the impacts of urban and rural water pollution but also facilitate the implementation of ecological governance, leading to measurable improvements in water quality.

4. Conclusion

In light of the increasingly serious problem of water pollution, studying the impact of urban and rural water pollution, as well as the ecological governance model from the perspective of aquatic ecology, holds significant practical importance. This research analyzes the effects of urban and rural water pollution on the soil, groundwater, and agricultural environments. In terms of the soil environment, all areas are categorized as lightly polluted, while Areas 3 and 4 are classified as heavily polluted. The primary cause of this pollution is the concentration of industrial and agricultural activities. Industrial wastewater and livestock effluent are discharged into the environment without adequate treatment. Regarding the groundwater environment, Areas 1 and 2 exhibit the highest levels of pollution, while other areas show relatively lower contamination. This is attributed to the fact that these areas are rural gathering zones where sewage discharge is seldom treated regularly. Additionally, rivers traversing these areas contribute to runoff pollution, allowing contaminants to enter the groundwater layer directly. With respect to the agricultural environment, an increase in the pollution degree of the irrigation water source correlates with a decrease in the emergence rate, yield, and dry matter content of crops. This trend indicates that as water pollution intensifies, the adverse effects on the agricultural environment become more pronounced. Following the application of the research methods, the highest concentration of water pollution has been reduced by 0.8 mg/L, resulting in overall data that remain below 1.0 mg/L, indicating a successful reduction in water pollution concentration. This study offers a new perspective on urban and rural water pollution and its ecological governance. It not only enriches the theoretical framework for water pollution control but also provides a scientific basis for the formulation of effective policies and measures.

5. Declarations

5.1. Author Contributions

Conceptualization, Y.H. and X.S.; methodology, Y.H.; formal analysis, N.S.; investigation, N.S. and Y.W.; resources, B.Q.; data curation, Y.H.; writing—original draft preparation, N.S.; writing—review and editing, Y.H.; supervision, Y.H.; project administration, Y.H. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.4. Acknowledgments

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5.5. Institutional Review Board Statement

Not applicable.

5.6. Informed Consent Statement

Not applicable.

5.7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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