International Journal of Natural Resources and Environmental Studies
ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 8, Number 7, Year 2026
DOI: https://doi.org/10.62051/ijnres.v8n7.02
Journal homepage: https://wepub.org/index.php/IJNRES/index

Construction and Enhancement of Ecological Buffer Zones in Rural Water Sources: A Case Study of the Duihekou Reservoir in Deqing County, Huzhou City, China

Mengyao Yuan*

University of Toronto, Toronto, Canada

*Corresponding Author: Mengyao Yuan (yukiyuki.yuan@mail.utoronto.ca)

ABSTRACT

This study aims to take the Duihekou Reservoir in Deqing County, Huzhou City, China as a case study to explore key issues in the construction and enhancement of ecological buffer zones for rural water sources, analyze the construction outcomes and existing challenges, and propose optimization measures. The research findings indicate that the ecological buffer zone construction of the reservoir has achieved significant results in improving water quality and enhancing ecosystem stability, yet it also faces ecological and management challenges such as a monotonous vegetation structure and inadequate management and maintenance. Based on these findings, the study proposes ecological restoration measures which including optimizing vegetation structure and strengthening wetland rehabilitation, as well as management optimization strategies such as establishing comprehensive management systems and enhancing interdepartmental collaboration, along with social participation initiatives like fostering public engagement mechanisms and implementing ecological compensation programs, aiming to provide valuable insights for the construction and enhancement of ecological buffer zones in other rural water sources.

KEYWORDS

Rural water sources; Ecological buffer zones; Duihekou Reservoir; Ecological restoration; Construction and improvement.

1. INTRODUCTION

1.1. Research Background

The Duihekou Reservoir is located in Deqing County, Zhejiang Province, with a total capacity of 146.9 million cubic meters. Its functions include flood control, water supply, irrigation, power generation, and aquaculture. In recent years, the reservoir has faced water quality issues caused by agricultural non-point source pollution, domestic sewage, and industrial wastewater, resulting in elevated total nitrogen and phosphorus concentrations that have led to eutrophication and cyanobacterial blooms. The reservoir hosts a rich diversity of phytoplankton and animal species, exhibiting distinct seasonal and spatial variations. Against this backdrop, the establishment of ecological buffer zones is widely recognized as a critical measure for ensuring water quality safety in water sources. Through vegetation restoration and wetland construction, these zones effectively intercept pollutants, reduce flow velocity, and enhance water self-purification capacity, thereby serving as a vital ecological barrier [3]. However, the width, vegetation density, and management of ecological buffer zones still require optimization. Therefore, in-depth research on the development and enhancement of ecological buffer zones in rural water sources holds significant practical importance.

1.2. Problem Statement

Although significant progress has been made in the theoretical and technical aspects of ecological buffer zones, numerous challenges remain to be addressed during their practical implementation and enhancement. Firstly, the current development of rural water source ecological buffer zones lacks unified standards and guidelines, resulting in substantial variations across regions in planning, design, technology selection, and construction practices, which hinders the establishment of a systematic protection framework [2]. Secondly, inadequate post-construction management and maintenance constitute another critical issue. Due to funding shortages, insufficient technical support, and ineffective interdepartmental coordination mechanisms, many established buffer zones fail to sustain their intended ecological functions and even experience degradation [5]. Additionally, low public engagement further limits the long-term effectiveness of these zones, compounded by residents' limited awareness of ecological conservation and the potential threats posed by agricultural activities. Against this backdrop, this study focuses on the estuary reservoir in Deqing County, Huzhou City, aiming to analyze its ecological buffer zone development practices, identify common challenges, and propose targeted solutions to serve as a reference for other rural water source areas.

1.3. Research Objectives

This study takes the Duihekou Reservoir in Deqing County, Huzhou City, as a case study, aiming to develop an effective model applicable to rural water sources through a comprehensive analysis of its ecological buffer zone development practices, thereby providing replicable insights for other regions. Specifically, the research objectives encompass the following aspects: First, systematically reviewing the construction history of the Duihekou Reservoir's ecological buffer zone and analyzing the technical approaches and management models employed during the planning, design, and implementation phases; Second, evaluating the practical outcomes of the buffer zone development in improving reservoir water quality and enhancing ecosystem stability, while identifying existing ecological, managerial, and social challenges; Finally, proposing targeted enhancement strategies which including optimizing ecological restoration measures, refining management systems, and establishing community engagement mechanisms[9]. By achieving these objectives, the study aims to provide theoretical foundations and practical guidance for the scientific development and sustainable management of ecological buffer zones in rural water source areas.

2. LITERATURE REVIEW

2.1. Theoretical Basis of Ecological Buffer Zones

An ecological buffer zone refers to a vegetated strip or ecosystem of defined width established around water sources, primarily functioning to intercept pollutants from surface runoff through physical, chemical, and biological processes, thereby reducing the influx of nutrients and contaminants into water bodies. Depending on their functions and locations, ecological buffer zones can be categorized into riverbank buffer zones, lakeshore buffer zones, and farmland buffer zones. Their core ecological principle involves leveraging the soil-stabilizing effect of vegetation roots to enhance soil permeability, while removing nutrients such as nitrogen and phosphorus and heavy metal pollutants through plant absorption and microbial degradation[6]. Studies indicate that ecological buffer zones effectively mitigate the impact of agricultural non-point source pollution on water environments and improve water quality in water sources to some extent. Additionally, these zones serve multiple functions, including microclimate regulation, biodiversity protection, and provision of ecosystem services, making them highly valuable for rural water source conservation[1].

2.2. Research Progress on Ecological Buffer Zones for Rural Water Sources Domestically and Internationally

In recent years, scholars worldwide have conducted extensive research on the establishment and management of ecological buffer zones around rural water sources. Domestically, studies on constructing ecological buffer zones for drinking water sources have progressed significantly, particularly in the Yangtze River Basin and southeastern coastal regions. Practical evidence demonstrates that well-planned ecological buffer zones substantially enhance water quality safety [3]. For instance, in protection projects for county-level and above drinking water sources in Hebei Province, these buffer zones have been widely implemented in primary protection zone isolation and ecological restoration initiatives, yielding positive outcomes [4]. However, China's rural water source buffer zone development still faces challenges such as irrational spatial planning and insufficient systematic integration, especially in areas with severe agricultural non-point source pollution, where the effectiveness of buffer zones remains limited[10]. In contrast, international practices—such as those in the United States and EU countries which establish rigorous laws, regulations, and technical standards ensure scientific planning and sustainable management of ecological buffer zones[7]. These global experiences offer valuable insights for optimizing rural water source buffer zone development in China.

2.3. Research Gaps

Although existing literature has extensively explored the theories and practices of ecological buffer zones in rural water source areas, several critical research gaps remain unresolved. Firstly, current studies predominantly focus on the singular functions or localized effects of these buffer zones, lacking systematic investigations into their entire development and enhancement processes—particularly regarding the evaluation of their applicability under diverse geographical conditions [2]. Secondly, research on the synergy between ecological buffer zone development and local economic growth remains insufficient; how to achieve sustainable regional economic development while safeguarding water source ecological security remains an unresolved challenge [4]. Additionally, studies on long-term monitoring and dynamic assessment of ecological buffer zones are relatively scarce, which somewhat limits the scientific rigor of management decisions. Addressing these gaps, this paper employs the Duihekou Reservoir in Deqing County, Huzhou City, as a case study to propose novel approaches and methodologies for constructing and enhancing ecological buffer zones in rural water source areas[2][4].

3. OVERVIEW OF THE DUIHEKOU RESERVOIR IN DEQING COUNTY, HUZHOU CITY

3.1. Geographical Location and Natural Environment

The Duihekou Reservoir is located in the western part of Deqing County, Huzhou City, Zhejiang Province, situated in the hilly terrain of the Tianmu Mountain foothills. The region features predominantly low mountains and hills with a topography that slopes higher in the west and lower in the east, boasting an average elevation ranging from 50 to 300 meters. The slopes around the reservoir typically measure between 15° and 30°, characteristic of a typical water conservation zone [9]. Climatically, Deqing County experiences a subtropical monsoon climate with distinct seasons and abundant rainfall, featuring an annual average temperature of approximately 16.1°C and annual precipitation between 1,300 and 1,600 millimeters. Precipitation is primarily concentrated during the plum rain season (late spring to early summer) and the summer typhoon season. This natural environment provides the reservoir with rich water resources, but also determines the ecosystem's sensitivity and fragility. The complex topography and abundant rainfall impose stringent requirements for establishing an ecological buffer zone around the water source, including designing tailored vegetation restoration strategies for varying slopes and soil types while addressing potential soil erosion risks caused by heavy rainfall [9].

Furthermore, the western region of Deqing County, where the Duihekou Reservoir is located, serves as one of Zhejiang Province's critical ecological barriers. The area boasts high forest coverage and rich biodiversity, providing a solid foundation for establishing an ecological buffer zone. However, due to significant topographical variations, certain areas surrounding the reservoir pose geological hazard risks such as landslides and debris flows, which require heightened attention during buffer zone development. Through scientific vegetation planning and ecological engineering techniques, these risks can be effectively mitigated while enhancing the buffer zone's ecological services. Thus, the natural environmental characteristics of the Duihekou Reservoir not only underscore its importance as a drinking water source but also offer unique natural conditions conducive to ecological buffer zone construction.

3.2. Functions and Status of the Reservoir

As a critical drinking water source for Deqing County, the Duihekou Reservoir plays an irreplaceable role in rural water supply, agricultural irrigation, and ecological regulation. In terms of water supply, it provides domestic water for approximately 150,000 residents in western townships, with a daily water delivery exceeding 20,000 tons. For agricultural irrigation, the reservoir serves over 12,000 mu (about 800 hectares) of farmland, effectively alleviating water shortages during dry seasons. In ecological regulation, the reservoir helps regulate climate and conserve water resources, achieving a pollutant interception efficiency of over 60% and significantly improving water quality. With the advancement of ecological civilization initiatives, its functions have expanded to include ecological protection and green development. In summary, the reservoir's multifunctional nature makes it central to the socio-economic development of western Deqing County, making enhanced protection efforts particularly urgent—ensuring water supply security while maintaining ecological stability.

3.3. Overview of the Reservoir and Analysis of Ecological Issues

3.3.1. Overview of the Reservoir

Located in Deqing County, Zhejiang Province, this reservoir is a large-scale water body primarily designed for flood control, while also serving multiple functions, including water supply, irrigation, power generation, and aquaculture. With a total storage capacity of 146.9 million cubic meters and a water surface area of approximately 7,000 mu (about 467 hectares), its strategic geographical location makes it the primary source of drinking water for the region. However, in recent years, the development of industrial and agricultural production in the area coupled with rising living standards among residents has led to increasingly severe ecological and environmental challenges facing the reservoir.

3.3.2. Current Status of Water Quality Pollution

The water quality pollution in this reservoir primarily stems from agricultural non-point source pollution, rural domestic sewage, and some industrial wastewater. According to the survey, the annual average total nitrogen concentration in the reservoir was 1.41 mg/L in 2025, exhibiting significant seasonal fluctuations with the highest levels in February and the lowest in April. The annual average total phosphorus concentration was 0.017 mg/L. These indicators indicate elevated nutrient levels in the reservoir, leading to pronounced eutrophication of the water body.

Table 1 Water Quality Data for Duihekou Reservoir of Deqing County in 2025

Dwell time	Water temperature	pH	Dissolved oxygen	Permanganate index	Chemical oxygen demand	Five-day BOD	Ammonia nitrogen	Total phosphorus	Total nitrogen	Copper	Zinc	Fluoride	Water quality classification
	(℃)		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
2025/1/2	9	7	13	1.4	8	0.7	0.03L	0.01	2.01	0.006L	0.004L	0.237	I
2025/2/11	7.5	7	10.4	1.4	12	0.9	0.03L	0.01	2.02	0.006L	0.004L	0.255	I
2025/3/12	11.2	7	11.6	1.6	7	0.9	0.03L	0.02	1.04	0.006L	0.004L	0.285	II
2025/4/11	19.2	9	9.4	1.9	10	1.3	0.03L	0.02	0.78	0.006L	0.004L	0.278	II
2025/5/13	22.7	9	11.7	3.6	13	1.6	0.03L	0.02	1.19	0.006L	0.004L	0.287	II
2025/6/9	24.8	9	8.7	2.2	7	1	0.03L	0.02	1.48	0.006L	0.004L	0.268	II
2025/7/4	31.3	9	9	2.6	8	1.3	0.05	0.02	1.57	0.006L	0.004L	0.282	II
2025/8/6	30.6	9	8.7	3	12	1.1	0.04	0.02	1.3	0.006L	0.004L	0.272	II
2025/9/3	30.6	9	7.4	2.9	12	1.2	0.03L	0.01	1.78	0.006L	0.004L	0.303	II
2025/10/16	26.3	7	7.6	2.2	9	1.1	0.03L	0.02	1.32	0.006L	0.004L	0.291	II
2025/11/1	20.1	7	8.5	1.6	5	1.4	0.14	0.02	1.07	0.006L	0.004L	0.247	II

3.3.3. Plankton Community Structure

The investigation revealed that the reservoir hosts abundant planktonic communities, comprising both phytoplankton and zooplankton. The phytoplankton primarily consists of the phyla Chlorophyta, Diatoms, Cyanobacteria, Chrysophyta(Nymphaea), and Cryptomonads, with Chlorophyta accounting for the largest proportion. The zooplankton community is mainly composed of rotifers, copepods, and copepods. Both phytoplankton and zooplankton exhibit significant seasonal and spatial variations: phytoplankton diversity peaks in winter and declines in summer, while their density and biomass are highest at the reservoir outlet and lowest near the dam. Due to the pronounced influence of water temperature on zooplankton, their density and biomass reach their maximum in April.

3.3.4. Fish Resources and Structure

The reservoir has recorded a total of 21 fish species, with silver carp and bighead carp being the dominant species. Both the fish population density and species composition are influenced by seasonal and environmental variations. Fish density peaks in spring, during which body length and weight increase more rapidly. As filter-feeding species, silver carp and bighead carp play a crucial role in controlling algal proliferation. Changes in fish growth rates and fishing pressure also exert complex impacts on the reservoir ecosystem. Existing fish stocking strategies require optimization to balance fishery production and ecological conservation.

3.3.5. Ecological Issues and Challenges

The primary ecological challenges facing this reservoir include water eutrophication, abnormal algal proliferation, and unstable ecosystem structure. Excessively high nutrient concentrations trigger algal blooms, compromising water quality and ecological balance. Agricultural activities and domestic wastewater discharge from surrounding communities constitute the main pollution sources, yet effective pollution control measures remain inadequate. Furthermore, the reservoir's ecological buffer zone development is incomplete, with vegetation degradation and weakened wetland functions, preventing it from fully fulfilling its ecological barrier role. Existing environmental management systems and emergency response mechanisms also exhibit deficiencies, rendering them ineffective in addressing sudden pollution incidents and transboundary environmental issues.

In summary, the reservoir must implement systematic and comprehensive ecological protection and restoration measures, optimize the construction and management of ecological buffer zones, and achieve improved water quality as well as sustainable ecosystem development.

3.4. Surrounding Social Environment

The socio-environmental conditions surrounding the Duihekou Reservoir are complex, with factors such as population distribution, industrial structure, and land use exerting profound impacts on the establishment and protection of the ecological buffer zone. Within a 5-kilometer radius, there are eight administrative villages with a permanent population of approximately 25,000, over 70% of whom are engaged in agriculture. The dispersed population distribution poses challenges for ecological management and may compromise water quality safety due to resident activities. Agriculture dominates the local economy, with primary crops including tea and bamboo shoots; however, excessive use of chemical fertilizers and pesticides has led to non-point source pollution. Meanwhile, the growth of rural tourism has increased wastewater and waste discharge, exacerbating the conflict between ecological conservation and economic development. Land use consists mainly of forested areas and farmland, though steep-slope farmland suffers from soil erosion and exhibits a monotonous forest structure. Additionally, the expansion of construction land may damage the ecological buffer zone, underscoring the need to balance ecological protection with economic development.

4. PRACTICES IN THE CONSTRUCTION OF THE ECOLOGICAL BUFFER ZONE FOR THE ESTUARY RESERVOIR

4.1. Construction Process

The development of the ecological buffer zone at the Duihekou Reservoir originated from the establishment of Deqing County's ecological protection compensation mechanism. During the planning phase, Deqing County pioneered a county-level compensation framework, designating the reservoir as a key protected area and establishing a tiered compensation system that laid the policy foundation for subsequent initiatives. In the implementation phase, the focus shifted from isolated vegetation restoration to comprehensive restoration projects encompassing wetland rehabilitation and ecological bank protection, aiming to systematically enhance ecological services and support sustainable community development. The objectives evolved progressively: initial efforts concentrated on building an ecological barrier, mid-phase efforts focused on comprehensively improving ecological functions, while later stages emphasized balancing ecological and socio-economic benefits. This phased approach ensured the project's scientific rigor and feasibility, serving as a replicable model for ecological conservation practices in rural water source areas.

4.2. Technical Measures Adopted

During the development of the ecological buffer zone at the estuary reservoir, a comprehensive array of ecological technologies has been employed to achieve multiple objectives: pollution interception, ecological restoration, and biodiversity conservation. Firstly, vegetation restoration serves as a cornerstone of the buffer zone construction. By selecting and configuring vegetation species with strong pollution tolerance and robust root systems, such as reeds and cattails that a multi-layered vegetation community structure has been established. This vegetation configuration not only effectively intercepts nutrients and pollutants from surface runoff but also stabilizes soil through root systems, reducing soil erosion. Secondly, the application of ecological bank protection technologies further enhances the stability and ecological functions of the buffer zone. Specifically, flexible banks constructed using eco-friendly materials like natural stone and ecological concrete avoid the disruptive effects of traditional rigid banks on ecosystems while providing habitat for aquatic organisms. Additionally, wetland construction techniques play a pivotal role in the buffer zone development. Through the design and implementation of artificial wetlands, the pollutant absorption, transformation, and degradation capabilities of wetland plants significantly improve water purification efficiency[6]. The integrated application of these technologies not only demonstrates the innovative application of ecological engineering principles but also provides technical support for similar ecological buffer zone developments in rural water source areas.

4.3. Construction Outcomes

The implementation of ecological buffer zones at the estuary reservoir has yielded significant results in improving water quality and enhancing ecosystem stability. Recent water quality monitoring data indicate a declining trend in total phosphorus (TP) content in the reservoir's surface sediments, particularly in the downstream damfront area, where phosphorus pollution has been effectively mitigated. Studies show that the vegetation cover and wetland systems within the buffer zones intercept 60%-80% of nutrients such as nitrogen and phosphorus, substantially reducing the impact of agricultural non-point source pollution on reservoir waters[3]. Additionally, changes in biodiversity indicators further demonstrate the positive outcomes of these buffer zones. Ecological surveys of the reservoir and surrounding areas reveal a 20% increase in phytoplankton species diversity and a marked rise in benthic animal diversity indices, indicating gradual restoration of ecosystem health[4]. These achievements not only highlight the buffer zones' effectiveness in pollutant interception and water purification but also provide empirical support for their widespread application in protecting rural water sources. Moreover, the development of ecological buffer zones has generated substantial socio-economic benefits, such as boosting local residents' incomes through rural leisure tourism and homestay economies, fostering a virtuous cycle between ecological conservation and economic growth[8].

5. EXISTING ISSUES IN THE ECOLOGICAL BUFFER ZONE OF THE ESTUARY RESERVOIR

5.1. Ecological Issues

The ecological buffer zone of the Duihekou Reservoir suffers from a monotonous vegetation structure, dominated by herbaceous species with a lack of multi-layered configurations of trees and shrubs. This results in a simplistic ecosystem structure and reduced stability, thereby diminishing its pollutant interception and purification capacity and significantly lowering the removal efficiency of nutrients such as nitrogen and phosphorus. Furthermore, the region exhibits a trend of ecological degradation, manifested by decreased wetland vegetation coverage, impaired soil aeration, and weakened microbial activity. These factors collectively compromise the system's purification capabilities and may even trigger the re-release of deposited nutrients, leading to secondary water pollution. Lastly, declining biodiversity exacerbates ecosystem vulnerability; reduced diversity in plant and animal communities directly compromises ecosystem services and threatens the long-term stability of water source ecosystems[1][7].

5.2. Management Issues

Management and maintenance efforts are inadequate. Due to insufficient funding and human resource allocation, fundamental maintenance tasks such as vegetation pruning, waste removal, and water quality monitoring have not been effectively carried out, impairing the proper functioning of the buffer zone. Additionally, the absence of a monitoring mechanism leads to delayed problem identification and resolution. Secondly, cross-departmental coordination mechanisms are ineffective; responsibilities among relevant government authorities are poorly defined, often resulting in buck-passing or redundant efforts. The lack of effective communication and collaboration among departments reduces overall prevention and control efficiency. Furthermore, the management system remains incomplete: there is no systematic or scientific institutional framework, prohibitive regulations are vague, penalty measures lack clarity, and a sustainable funding mechanism has not been established, all of which hinder the long-term effective implementation of management practices [2][5].

5.3. Social Issues

Local residents exhibit relatively weak ecological conservation awareness. Due to insufficient public education and inadequate incentive mechanisms, their understanding of buffer zone functions remains limited, and participation rates are low. Incidents such as indiscriminate waste disposal and irrational agricultural activities occur frequently, not only damaging the environment but also complicating management efforts. Secondly, agricultural non-point source pollution poses significant challenges: excessive use of fertilizers and pesticides leads to substantial nutrient runoff into buffer zones, contaminating water quality. Although some optimization technologies and interception systems exist, their practical effectiveness is limited due to insufficient supporting policies and funding. Moreover, the dispersed and random nature of non-point pollution makes remediation particularly challenging [7][10]. Finally, a conflict exists between socioeconomic development and ecological protection, land development demands clash with buffer zone protection boundaries. During urbanization, buffer zone areas are often compressed or functionally impaired, directly threatening the safety of water source protection.

6. OPTIMIZATION PLANS AND MEASURES FOR ECOLOGICAL BUFFER ZONES

6.1. Increasing the width of ecological buffer zones and vegetation density

Increasing the width and vegetation density of ecological buffer zones is crucial for enhancing their ecological functions. Studies indicate that the width of an ecological buffer zone is directly proportional to its pollutant interception capacity. Building upon existing buffer zones, their width should be expanded to 30–50 meters, creating a multi-layered and diverse vegetation structure. By selecting locally adapted herbaceous plants, shrubs, and trees with well-developed root systems, an efficient ecological barrier can be established, improving pollutant adsorption and retention capabilities. This not only enhances the water purification capacity of the buffer zones but also provides habitats for various wildlife species, thereby boosting regional biodiversity.

6.2. Strengthening Wetland Protection and Restoration

Wetlands play a vital role in water purification and maintaining ecological balance. Restoring and protecting estuarine wetlands, along with cultivating aquatic plants such as reeds, cattails, and calamus, enhances their water purification capacity. By establishing wetland filtration systems that utilize the root systems and microbial communities of aquatic plants to decompose and absorb organic pollutants and nutrients from water, total nitrogen and phosphorus concentrations can be reduced. Additionally, wetland restoration provides crucial habitats for waterbirds and aquatic organisms, strengthening ecosystem stability and resilience.

6.3. Implementation of a Scientific Fish Stocking Strategy

Fish play a crucial regulatory role in aquatic ecosystems. Analysis based on the Ecopath model enables optimization of stocking strategies for silver carp and bighead carp. For instance, in the Qian Island Lake study, the Ecopath model was constructed using ecological and fishery resource data collected from 2008 to 2010 to assess the impact of silver carp and bighead carp stocking on the ecosystem. The results demonstrated that long-term stocking of these species significantly altered the food web structure of Qian Island Lake, with reduced complexity in nutritional interactions and decreased ecosystem maturity and stability. Furthermore, Ecopath-based stock enhancement studies revealed that the trophic levels of suitable stocking species ranged from 2.2 to 3.7, and the maximum carrying capacities for different species were estimated. For example, the maximum carrying capacity for silver carp was 0.094 t/km², while that for the ripples clams (Concha concha) reached 75.870 t/km².

6.4. Strengthening Control of Agricultural Non-point Source Pollution

Agricultural activities constitute one of the primary pollution sources for this reservoir. Promoting ecological agriculture and organic farming practices, reducing the use of chemical fertilizers and pesticides, and adopting scientific fertilization methods along with integrated pest management techniques can lower nitrogen and phosphorus levels in agricultural runoff[4]. Establishing farmland drainage systems and sedimentation ponds enables the interception and treatment of runoff, preventing its direct entry into the reservoir. Additionally, conducting environmental awareness campaigns and training programs for farmers enhances their ecological consciousness, thereby mitigating the impact of agricultural non-point source pollution on reservoir water quality at the source.

6.5. Improve the environmental management and monitoring system

Establish and improve environmental management and monitoring systems to ensure the long-term effectiveness of ecological buffer zones. Set up dedicated management agencies for these zones, clarify their responsibilities, develop management protocols and measures, and conduct regular maintenance and oversight. Establish a water quality monitoring network to track real-time changes in water quality within reservoirs and ecological buffer zones, enabling timely identification and mitigation of pollution issues. Utilize remote sensing and GIS technologies to dynamically monitor vegetation coverage and ecological conditions, thereby assessing the zones' ecological functions and performance. Scientific management and monitoring ensure the continuous optimization and efficient operation of ecological buffer zones.

These optimization strategies and measures can further enhance the functionality of the reservoir's ecological buffer zone, effectively improve water quality, protect biodiversity, and achieve sustainable development of the reservoir. Meanwhile, these experiences and practices hold significant reference value and practical implications for the ecological conservation and restoration of other similar water sources.

7. CONCLUSION

7.1. Research Findings Summary

The construction of the ecological buffer zone at the estuary reservoir has achieved significant results through technical measures such as vegetation restoration, ecological bank protection, and wetland development, leading to improved water quality (decreased total phosphorus levels and reduced phosphorus pollution in the downstream dam-head area) and enhanced ecosystem stability (restoration of biodiversity). However, ecological challenges remain, including a monotonous vegetation structure and degraded ecological functions; management issues such as inadequate maintenance and poor interdepartmental coordination; and social concerns like insufficient public awareness of ecological protection and threats from agricultural non-point source pollution. Accordingly, measures for ecological restoration, management optimization, and social participation have been proposed.

7.2. Insights into the Construction of Ecological Buffer Zones for Rural Water Sources

In terms of philosophy, emphasis is placed on the synergy between ecological protection and economic development, drawing on the experience of Zhejiang's ecological compensation system.

Technically, appropriate measures are selected based on the local natural environment; for instance, ecological interception systems combined with vegetation restoration and wetland construction are adopted in hilly and mountainous areas. In terms of management, long-term mechanisms are established and improved, with clear departmental responsibilities, enhanced collaboration, and mechanisms for public participation.

7.3. Research prospect

Future research should focus on systematic studies to optimize the spatial layout and enhance functional synergy mechanisms of buffer zones under diverse topographic conditions; examine the synergistic relationship between ecological buffer zones and local economic development, and explore market-based ecological compensation models; develop adaptive strategies to address emerging pollutants and extreme climate events; and strengthen tracking studies of successful domestic and international cases while summarizing the latest advancements in ecological technologies and management approaches.

REFERENCES

[1] Tan, L. X., Kang, D. J., Liu, C., Zhu, L. Z., Shen, Q. S., & Chen, K. N. (2024). Mechanism of phosphorus source-sink conversion at the sediment-water interface in reservoirs in hilly and mountainous areas. China Environmental Science, 44(4), 2137–2147.

[2] Shen, X. Y., & Wang, W. (2022). Practice and reflections on the county-level ecological protection compensation mechanism: A case study of Deqing County, Zhejiang Province. Regional Governance, (33), 21–25.

[3] Liu, Y. Q., Song, X. Q., & Zhang, D. (2022). Research on the environmental status and protection strategies of drinking water sources. Guangdong Chemical Industry, 49(19), 166–168.

[4] Fu, S. J., Zhao, N., Zhang, X. Q., Li, D., & Wan, B. C. (2022). Research on ecological and environmental protection projects for centralized drinking water sources. Contemporary Chemical Industry Research, (22), 93–95.

[5] Shen, M. H., Xie, H. M., Wang, J., Zhang, H., Shan, L., Chen, J., Liu, H. Q., & Yan, J. Y. (2015). The "Zhejiang Model" for establishing an ecological compensation system. Journal of the Zhejiang Provincial Committee of the Communist Party of China, 0(4), 45–52.

[6] Deng, R., Chen, Y. P., Li, Y. J., Liu, Y. Y., Shen, D. D., & Xiong, B. M. (2024). Research on the construction system of ecological isolation belts for important drinking water sources in the Yangtze River Basin. Water Resources Development Research, 24(4), 36–42.

[7] Wang, W. (2023). Exploring treatment methods for agricultural non-point source water pollution. Regional Governance, (3), 28–31.

[8] Zhong, J. L. (2022). Research on Huzhou's mechanism for realizing the value of ecological products. Zhejiang Economy, (12), 42–44.

[9] Luo, X. J. (2020). Exploration of the "Two Mountains" transformation path outside urban development boundaries: A case study of the Western Region of Deqing County, Zhejiang Province. Urban Planning, 44(S01), 41–46.

[10] Miao, Q., & Wang, J. (2021). Discussion on comprehensive water environment management technologies for small watershed river networks in East China. Waterways and Ports, 42(3), 376–383.