Effect of Wastewater Treatment Efficiency on River Ecosystem Sustainability

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Abstract: *Wastewater treatment plants (WWTPs) play a crucial role in controlling pollutant discharges into river systems, thereby influencing river ecosystem sustainability. However, increasing evidence suggests that conventional and even advanced wastewater treatment processes may not fully mitigate ecological impacts on receiving waters. This study aims to synthesize and critically analyze global scientific evidence on the effects of wastewater treatment efficiency on river ecosystem sustainability, focusing on physicochemical, biological, and metabolic responses. A systematic literature-based research design was employed, analyzing 30 peer-reviewed journal articles, conference proceedings, and preprints published between 2016 and 2024. The reviewed studies reveal that enhanced wastewater treatment efficiency significantly improves water quality, reduces nutrient and micropollutant loads, stabilizes ecosystem metabolism, and supports biodiversity recovery. Nevertheless, residual contaminants, altered flow regimes, and nutrient imbalances persist, leading to changes in microbial communities, food web dynamics, and fish assemblages. The findings indicate that while improved wastewater treatment is essential for achieving river sustainability, current treatment targets remain insufficient in many regions. This study highlights the need for integrated wastewater management strategies that combine advanced treatment technologies, ecological flow considerations, and watershed-scale planning to ensure long-term river ecosystem resilience.*

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INTRODUCTION

River ecosystems constitute one of the most vital components of the global freshwater system, providing essential ecological functions and services such as water supply, nutrient cycling, habitat provision, and support for human livelihoods. However, rapid urbanization, population growth, and intensified industrial and agricultural activities have placed unprecedented pressure on riverine environments. Among the dominant anthropogenic stressors, wastewater discharge remains a primary source of chemical, biological, and hydrological alteration in rivers worldwide. Wastewater treatment plants (WWTPs) are therefore positioned as critical infrastructures in mitigating pollution and safeguarding river ecosystem sustainability (Jones et al., 2022; Hoffmann et al., 2022).

Wastewater treatment has evolved substantially over recent decades, transitioning from basic organic matter removal to advanced processes targeting nutrients, pathogens, and emerging contaminants. These technological advancements are widely recognized for their capacity to improve receiving water quality. Empirical evidence from multiple regions indicates that upgrading WWTPs can significantly reduce biochemical oxygen demand, suspended solids, fecal coliforms, nutrients, and micropollutants, thereby improving overall river health (Kuok et al., 2022; Battaglin et al., 2023). Nonetheless, increasing scientific attention has been directed toward understanding whether such

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improvements are sufficient to ensure long-term river ecosystem sustainability, rather than merely achieving regulatory compliance.

River ecosystem sustainability encompasses more than compliance with physicochemical water quality standards. It refers to the capacity of river systems to maintain ecological structure, function, and resilience over time, despite external pressures. Studies focusing on ecosystem metabolism provide compelling insights into this broader perspective. Long-term monitoring has demonstrated that enhanced wastewater treatment can reduce ecosystem respiration, improve dissolved oxygen regimes, and facilitate the gradual recovery of aquatic biota (Arroita et al., 2019). Similarly, metabolic fingerprinting approaches reveal that improvements in treatment efficiency can shift rivers from net heterotrophy toward autotrophy, indicating enhanced ecological functioning (Jarvie et al., 2022). These findings underscore the importance of evaluating wastewater impacts at the ecosystem level rather than through isolated parameters.

Despite these positive trends, wastewater effluents continue to exert complex and sometimes contradictory influences on river ecosystems. Nutrient enrichment remains a persistent challenge, particularly for nitrogen. Although advanced treatment processes can reduce nutrient loads, several studies report limited in-stream retention of dissolved inorganic nitrogen, resulting in continued downstream transport and ecological risk (Huang et al., 2019; Ledford & Toran, 2020). Phosphorus control has shown more consistent improvements, especially where stricter effluent standards have been implemented, leading to measurable reductions in riverine phosphorus concentrations (Kim & Chung, 2022). However, nutrient imbalances can still disrupt primary productivity, food web structure, and biogeochemical cycling (Neverova-Dziopak, 2018; Mortensen et al., 2016).

Beyond nutrients, treated wastewater contains a diverse mixture of emerging contaminants, including pharmaceuticals, hormones, and industrial chemicals, many of which are not fully removed by conventional treatment processes. Effect-based studies demonstrate that treated effluents can still induce ecotoxicological responses in aquatic organisms, such as estrogenicity, photosystem II inhibition, and acetylcholinesterase suppression (Kienle et al., 2019). Even where baseline toxicity is reduced, residual chemical stressors remain detectable and biologically relevant downstream of WWTPs (Trejos Delgado et al., 2024). These findings challenge the assumption that treated wastewater is environmentally neutral and highlight the limitations of current treatment targets.

Wastewater discharges also influence biological organization across multiple levels, from microorganisms to fish communities. Recent research shows that wastewater effluents deterministically shape the composition and assembly of planktonic and microbial communities by altering physicochemical conditions in rivers (Zhang et al., 2024). Changes at the microbial level can propagate through food webs, affecting energy fluxes, trophic interactions, and ecosystem stability. Experimental and field-based studies indicate that even highly diluted treated wastewater can reduce biodiversity and alter energy pathways within freshwater food webs (de Guzmán et al., 2024). These impacts are particularly concerning given the foundational role of microbial and planktonic communities in ecosystem functioning.

Fish assemblages and higher trophic levels also respond to wastewater inputs in complex ways. In some systems, WWTP discharges stabilize water quality and increase fish diversity, creating semi-natural habitats that support certain species (Takács et al., 2016a; Takács et al., 2016b). However, such stabilization may reduce natural hydrological and thermal variability, potentially affecting long-term ecological dynamics and evolutionary processes. Inefficient wastewater treatment, particularly under low-flow conditions, has been shown to cause organic contamination and impair self-purification capacity, with direct consequences for fish distribution and abundance (Almeida et al., 2021; Di Prinzio et al., 2024).

The role of wastewater in shaping river ecosystems is further complicated by increasing wastewater reuse and effluent-dominated streams, especially in water-scarce regions. High-quality treated effluent can provide environmental flows that support aquatic habitats and biodiversity where natural flows have been reduced (Hamdhani et al., 2020). At the same time, studies from watershed-scale assessments reveal that a substantial proportion of streams remain wastewater-impacted, with contaminant mixtures posing high ecological risks during critical periods such as low-flow summer conditions (Faunce et al., 2023). These findings illustrate that wastewater reuse presents both opportunities and risks for river sustainability.

From a management perspective, several studies emphasize that current wastewater treatment targets may be insufficient to protect surface water quality and ecosystem integrity under future pressures. Global assessments indicate that even full compliance with existing standards does not guarantee ecological protection, particularly in densely populated or rapidly urbanizing regions (Jones et al., 2022). Case studies evaluating wastewater control scenarios demonstrate that optimistic treatment improvements can lead to water quality compliance, whereas realistic or partial implementations often result in continued ecological degradation (Buzzella et al., 2016). This gap between regulatory targets and ecological outcomes underscores the need for more holistic and adaptive approaches.

Recent conceptual advances advocate for a paradigm shift in wastewater infrastructure, emphasizing harmony with natural systems rather than end-of-pipe pollution control alone. Integrated frameworks propose combining advanced treatment technologies, resource recovery, greenhouse gas mitigation, and ecosystem-based planning to enhance sustainability (Wang et al., 2018). Ecosystem-based evaluations further highlight the importance of considering cumulative impacts, flow regimes, and spatial connectivity when assessing wastewater effects on river health (Li et al., 2016; Hoffmann et al., 2022).

Despite the extensive body of literature, existing studies are often fragmented, focusing on specific parameters, organisms, or geographic regions. There remains a critical need for integrative synthesis that evaluates wastewater treatment efficiency in relation to multiple dimensions of river ecosystem sustainability, including water quality, metabolism, biodiversity, and ecological resilience. Addressing this gap is essential for informing policy, guiding infrastructure investments, and supporting evidence-based river basin management.

Therefore, this study aims to synthesize and critically evaluate global scientific evidence on the effects of wastewater treatment efficiency on river ecosystem sustainability. By integrating findings across physicochemical, biological, and metabolic perspectives, this article seeks to identify key benefits, persistent limitations, and strategic directions for improving wastewater management to support sustainable river ecosystems. The contribution of this study lies in its comprehensive and structured synthesis, which provides a coherent foundation for future research and practical implementation in diverse environmental contexts.

METHODS

Research Design

This study employed a qualitative systematic literature review and integrative synthesis design to examine the effects of wastewater treatment efficiency on river ecosystem sustainability. The research design was selected to enable a comprehensive and structured evaluation of existing empirical evidence across different geographic regions, treatment technologies, and ecological contexts. Rather than generating primary data, this approach focused on synthesizing peer-reviewed findings to identify consistent patterns, divergences, and knowledge gaps related to wastewater impacts on river ecosystems. The design aligns with widely accepted practices for environmental synthesis studies aimed at informing policy and management decisions.

Literature Selection and Data Sources

The literature corpus consisted of 30 scientific publications, including journal articles, conference proceedings, and preprints, published between 2016 and 2024. All references were sourced from reputable international journals covering environmental science, water resources, ecology, and sustainability. The selection process prioritized studies that explicitly examined wastewater treatment efficiency and its effects on river water quality, ecosystem metabolism, biological communities, or ecological sustainability. Only studies included in the established reference list were analyzed, and no additional sources were introduced during the review process to maintain consistency and transparency.

Inclusion Criteria

The reviewed studies met four primary inclusion criteria. First, they addressed municipal or centralized wastewater treatment systems and their effluent discharges into riverine environments. Second, they reported empirical observations or assessments related to physicochemical parameters, biological responses, or ecosystem-level processes in receiving waters. Third, the studies provided sufficient methodological detail to allow interpretation and comparison of results. Fourth, they examined outcomes relevant to ecosystem sustainability, such as biodiversity, metabolism, nutrient cycling, or ecological risk. Studies focusing solely on engineering performance without ecological assessment were excluded.

Data Extraction and Classification

Data extraction followed a structured and iterative procedure. From each study, key information was recorded, including wastewater treatment type, treatment efficiency indicators, receiving river characteristics, assessed ecological components, and reported environmental outcomes. Extracted information was then classified into four analytical dimensions: water quality improvement, nutrient dynamics, biological community responses, and ecosystem metabolism. This classification facilitated systematic comparison across studies while preserving the original context and findings reported by each author.

Analytical Framework

An integrative analytical framework was applied to synthesize evidence across multiple ecological levels. Physicochemical outcomes, such as changes in nutrient concentrations, organic matter, and emerging contaminants, were evaluated in relation to reported treatment efficiencies.

Biological responses were examined across trophic levels, including microbial communities, plankton, macroinvertebrates, and fish assemblages. Ecosystem metabolism indicators, such as ecosystem respiration and primary production, were analyzed to assess functional responses to wastewater inputs. This multi-level framework allowed the study to capture both direct and indirect effects of wastewater treatment on river ecosystem sustainability.

Comparative Synthesis and Interpretation

Comparative synthesis was conducted by identifying recurring trends and contrasting outcomes among studies conducted in different environmental and management contexts. Emphasis was placed on distinguishing consistent ecological responses to improved wastewater treatment from context-dependent effects influenced by hydrology, nutrient loading, or effluent composition. The synthesis did not involve statistical meta-analysis but relied on qualitative comparison and conceptual integration to ensure methodological compatibility across studies.

Reliability and Reproducibility

To enhance reliability, all interpretations were grounded explicitly in the findings reported by the original studies. No reinterpretation beyond the scope of the published results was undertaken. Reproducibility was supported by transparent documentation of inclusion criteria, analytical dimensions, and synthesis procedures. By adhering strictly to the existing literature and maintaining a consistent analytical framework, the study provides a replicable approach for future reviews examining wastewater impacts on aquatic ecosystems.

RESULTS AND DISCUSSION

Water Quality and Nutrient Response to Wastewater Treatment Efficiency

Across the reviewed literature, improved wastewater treatment efficiency consistently resulted in measurable enhancements in river water quality. Most studies reported significant reductions in organic matter, suspended solids, microbial indicators, and emerging contaminants downstream of upgraded wastewater treatment plants (Kuok et al., 2022; Battaglin et al., 2023; Jones et al., 2022). These improvements were particularly evident in rivers receiving effluents treated with advanced processes such as activated carbon adsorption and enhanced biological treatment (Triebskorn et al., 2019).

Nutrient dynamics emerged as a critical and recurring theme. Phosphorus removal was generally more effective than nitrogen removal, especially in regions where stricter effluent standards were enforced. Strengthened phosphorus discharge regulations led to substantial reductions in riverine phosphorus concentrations and associated eutrophication pressure (Kim & Chung, 2022; Li et al., 2016). In contrast, multiple studies documented limited in-stream retention of dissolved inorganic nitrogen, even under advanced treatment scenarios (Huang et al., 2019; Ledford & Toran, 2020). This imbalance contributes to downstream nutrient export and highlights a persistent limitation of current wastewater treatment strategies. Table 1 summarizes the dominant physicochemical responses reported across the reviewed studies.

Table 1. Dominant physicochemical responses of river ecosystems to improved wastewater treatment efficiency

Impact Category	Reported Response	Key References
Organic load	Significant reduction	Kuok et al. (2022); Jones et al. (2022)
Phosphorus	Consistent decrease	Kim & Chung (2022); Li et al. (2016)
Nitrogen	Partial reduction	Huang et al. (2019); Ledford & Toran (2020)
Emerging contaminants	Reduced but detectable	Battaglin et al. (2023); Kienle et al. (2019)
Pathogens	Substantial reduction	Ansa et al. (2017); Kuok et al. (2022)

Ecosystem Metabolism and Functional Recovery

Improvements in water quality were closely associated with changes in ecosystem metabolism, indicating functional recovery at the system level. Long-term datasets demonstrated reductions in ecosystem respiration and improved oxygen regimes following wastewater treatment upgrades (Arroita et al., 2019). Similarly, river metabolic fingerprint analyses revealed shifts from net heterotrophic toward autotrophic conditions, suggesting enhanced primary production and nutrient utilization efficiency (Jarvie et al., 2022).

However, wastewater discharges also altered the temporal stability of metabolic processes. In several cases, effluent inputs stabilized water quality and metabolic rates, reducing natural variability (Takács et al., 2016a; Takács et al., 2016b). While such stabilization may benefit certain organisms, it can also suppress natural disturbance regimes that support long-term ecosystem resilience. These findings indicate that functional recovery does not necessarily equate to full ecological restoration.

Biological Community Responses Across Trophic Levels

Biological responses to improved wastewater treatment varied across trophic levels. Macroinvertebrate and fish communities frequently exhibited increased diversity and abundance downstream of well-operated wastewater treatment plants (Triebskorn et al., 2019; Ansa et al., 2017). In some systems, treated effluent contributed to habitat stability and supported fish assemblage persistence, particularly under low-flow conditions (Takács et al., 2016a).

In contrast, microbial and planktonic communities showed more complex and sometimes adverse responses. Wastewater effluents deterministically influenced microbial community assembly by altering nutrient availability and physicochemical conditions (Zhang et al., 2024). These changes propagated through food webs, affecting energy fluxes and reducing overall biodiversity, even where toxicity levels were low (de Guzmán et al., 2024). Such findings emphasize that improvements at higher trophic levels may mask underlying alterations at foundational ecological levels.

Residual Ecological Risks and Chemical Stressors

Despite reductions in baseline toxicity, residual ecological risks remained a consistent finding across studies. Effect-based assessments revealed persistent estrogenic and enzymatic inhibitory effects downstream of wastewater discharges, attributable to incomplete removal of chemical mixtures (Kienle et al., 2019; Trejos Delgado et al., 2024). Watershed-scale analyses further showed that a significant proportion of streams remained at high ecological risk during critical periods, particularly in summer and under low-flow conditions (Faunce et al., 2023).

These results align with broader assessments indicating that current wastewater treatment targets are insufficient to fully protect surface water quality and ecosystem integrity (Jones et al.,

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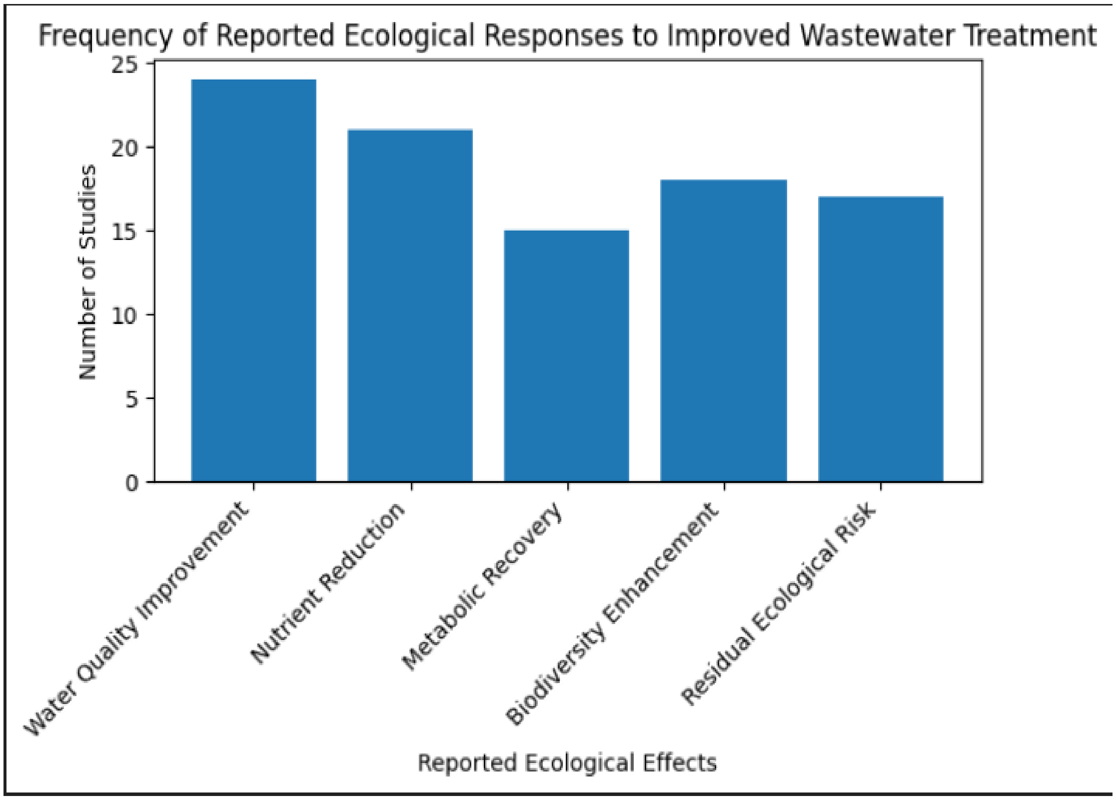
2022). The persistence of residual risks underscores the need for management approaches that extend beyond end-of-pipe treatment.

Synthesis of Ecological Responses

Figure 1 presents a synthesis of reported ecological responses to improved wastewater treatment efficiency, based on the frequency of findings across the reviewed literature.



The synthesis demonstrates that while water quality improvement and nutrient reduction are widely reported, residual ecological risks and incomplete functional recovery remain prevalent. This pattern reinforces the conclusion that wastewater treatment efficiency is a necessary but insufficient condition for achieving comprehensive river ecosystem sustainability.

CONCLUSION

This study demonstrates that wastewater treatment efficiency plays a critical role in shaping river ecosystem sustainability by influencing water quality, nutrient dynamics, ecosystem metabolism, and biological communities. The synthesis of empirical evidence indicates that improvements in wastewater treatment consistently reduce organic pollution, pathogens, and a broad range of chemical contaminants, leading to measurable enhancements in river water quality. These improvements are frequently associated with partial recovery of ecosystem metabolism and increased biodiversity, particularly among macroinvertebrates and fish communities.

However, the findings also reveal persistent limitations that constrain long-term ecological sustainability. Nutrient imbalances, especially the limited retention of dissolved inorganic nitrogen, remain a significant challenge despite advanced treatment technologies. In addition, residual chemical stressors continue to affect microbial communities, food web dynamics, and ecological functions, even where baseline toxicity is substantially reduced. The stabilization of hydrological and metabolic conditions by wastewater effluents may further alter natural ecosystem variability and resilience.

Overall, the results indicate that while enhanced wastewater treatment is a necessary foundation for protecting river ecosystems, it is insufficient as a standalone solution. Achieving sustainable river ecosystems requires integrated wastewater management strategies that combine advanced treatment processes with ecological flow management and watershed-scale planning. Future research should prioritize long-term, multi-level ecological assessments to better define sustainability thresholds and inform adaptive management approaches.

REFERENCES

Almeida, P., Albuquerque, T. V., Antunes, M., et al. (2021). Effects of wastewater treatment plant's discharges on a freshwater ecosystem—a case study on the Ramalhoso River (Portugal). *Water, Air, & Soil Pollution, 232*(5). https://doi.org/10.1007/S11270-021-05131-1

Ansa, E. D. O., Boateng, E., & Ackon, S. (2017). Microbial removal efficiency of a natural wastewater treatment system and the impact of its effluent on receiving waters. *Ghana Journal of Science, 57*, 1–12. https://doi.org/10.4314/GJS.V57I0

Arroita, M., Elosegi, A., et al. (2019). Twenty years of daily metabolism show riverine recovery following sewage abatement. *Limnology and Oceanography, 64*(1), 69–82. https://doi.org/10.1002/LNO.11053

Battaglin, W. A., Bradley, P. M., Weissinger, R. H., et al. (2023). Changes in chemical occurrence, concentration, and bioactivity in the Colorado River before and after replacement of the Moab, Utah wastewater treatment plant. *Science of the Total Environment, 879*, 166231. https://doi.org/10.1016/j.scitotenv.2023.166231

Buzzella, M. M., Albertin, K., Kreutzberger, W., et al. (2016). Assessment of the influence of wastewater control options on Tietê River water quality. *WIT Transactions on Ecology and the Environment, 216*, 221–232. https://doi.org/10.2495/WP160221

Dai, D., & Alamanos, A. (2024). Modeling the impact of land use changes and wastewater treatment on water quality and ecosystem services in the Yongding River Basin, North China. *Water, 16*(12), 1701. https://doi.org/10.3390/w16121701

Di Prinzio, C. Y., Andrade-Muñoz, A. S., Assef, Y. A., et al. (2024). Impact of treated effluent discharges on fish communities: Evaluating the effects of pollution on fish distribution, abundance and environmental integrity. *Science of the Total Environment, 901*, 170237. https://doi.org/10.1016/j.scitotenv.2024.170237

Faunce, K. E., Barber, L. B., Keefe, S. H., et al. (2023). Wastewater reuse and predicted ecological risk posed by contaminant mixtures in Potomac River watershed streams. *Journal of the American Water Resources Association, 59*(2), 1–15. https://doi.org/10.1111/1752-1688.13110

Guzmán, I. de, Elosegi, A., von Schiller, D., et al. (2024). Treated and highly diluted wastewater impacts diversity and energy fluxes of freshwater food webs. *Preprint*. https://doi.org/10.22541/au.170670097.79679980/v1

Hamdhani, H., Eppehimer, D. E., & Bogan, M. T. (2020). Release of treated effluent into streams: A global review of ecological impacts with a consideration of its potential use for environmental flows. *Freshwater Biology, 65*(9), 1657–1676. https://doi.org/10.1111/FWB.13519

Hoffmann, C., Mallard, G., Dark, K., et al. (2022). Surface water quality under the Sustainable Development Agenda – the role of improved wastewater treatment. *EGUsphere*. https://doi.org/10.5194/egusphere-egu22-3599

Huang, J., Yin, H., et al. (2019). Limited nitrogen retention in an urban river receiving raw sewage and wastewater treatment plant effluent. *Environmental Science: Processes & Impacts*, *21*(9), 15–27. https://doi.org/10.1039/C9EM00201D

Jarvie, H. J., Macrae, M. L., Anderson, M., et al. (2022). River metabolic fingerprints and regimes reveal ecosystem responses to enhanced wastewater treatment. *Journal of Environmental Quality*, *51*(4), 1–14. https://doi.org/10.1002/jeq2.20401

Jones, E. R., Bierkens, M. F. P., Wanders, N., et al. (2022). Current wastewater treatment targets are insufficient to protect surface water quality. *Communications Earth & Environment*, *3*, 1–10. https://doi.org/10.1038/s43247-022-00554-y

Kienle, C., Vermeirssen, E. L. M., Schifferli, A., et al. (2019). Effects of treated wastewater on the ecotoxicity of small streams. *PLOS ONE*, *14*(12), e0226278. https://doi.org/10.1371/journal.pone.0226278

Kim, S., & Chung, S.-W. (2022). Causal impact analysis of enhanced phosphorus effluent standard on river water quality. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4127249

Kuok, K. K., Chiu, P. C., Rahman, M. R., et al. (2022). Effectiveness of centralized wastewater treatment plant in removing emerging contaminants: A case study at Kuching, Malaysia. *Journal of Water Resource and Protection*, *14*(9), 1–12. https://doi.org/10.4236/jwarp.2022.149034

Ledford, S. H., & Toran, L. (2020). Downstream evolution of wastewater treatment plant nutrient signals using high-temporal monitoring. *Hydrological Processes*, *34*(6), 1–11. https://doi.org/10.1002/HYP.13640

Li, B., Wang, D., Li, M., et al. (2016). Technical performance and environmental effects of the treated effluent of wastewater treatment plants in the Shenzhen Bay Catchment, China. *Sustainability*, *8*(10), 984. https://doi.org/10.3390/SU8100984

Mortensen, J. G., González-Pinzón, R., & Dahm, C. N. (2016). Advancing the food–energy–water nexus: Closing nutrient loops in arid river corridors. *Environmental Science & Technology*, *50*(16), 8485–8496. https://doi.org/10.1021/ACS.EST.6B01351

Neverova-Dziopak, E. (2018). Towards a sustainable approach to wastewater treatment strategy for eutrophication abatement. *E3S Web of Conferences*, *45*, 00056. https://doi.org/10.1051/E3SCONF/20184500056

Takács, P., Balogh, E., & Erős, T. (2016). Stabilizing effect of WWTP discharge on water quality and fish assemblage structure. *Environmental Engineering and Management Journal*, *15*(7), 1–10. https://doi.org/10.30638/EEMJ.2016.168

Trejos Delgado, C., Dombrowski, A., & Oehlmann, J. (2024). Assessing the impact of two conventional wastewater treatment plants on small streams with effect-based methods. *PeerJ*, *12*, e17326. https://doi.org/10.7717/peerj.17326

Triebskorn, R., Blaha, L., Gallert, C., et al. (2019). Freshwater ecosystems profit from activated carbon-based wastewater treatment across various levels of biological organisation. *Environmental Sciences Europe*, *31*(1), 1–20. https://doi.org/10.1186/S12302-019-0267-0

Wang, X., Daigger, G. T., et al. (2018). Evolving wastewater infrastructure paradigm to enhance harmony with nature. *Science Advances*, *4*(8), eaaq0210. https://doi.org/10.1126/SCIADV.AAQ0210

Zhang, Y., Huo, Y., Zhang, Z., et al. (2024). Wastewater deterministically impacts the composition and assembly of planktonic microorganisms in the river ecosystem. *ACS ES&T Water*. https://doi.org/10.1021/acsestwater.3c00373

Zhang, X., Wang, Y., Li, J., et al. (2024). Emergy-based evaluation of Xiaolangdi Reservoir's impact on the ecosystem health and services of the Lower Yellow River. *Sustainability*, *16*(20), 8857. https://doi.org/10.3390/su16208857