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Impact Assessment of Biotreated Wastewater Effluent on Receiving Surface Water Quality

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Abstract

Rapid urbanization in tropical regions increases pressure on freshwater ecosystems through wastewater discharges. In Bujumbura (Burundi), treated effluent from the Buterere wastewater treatment plant (BWWTP) is discharged into the Kinyankonge River, which ultimately flows into Lake Tanganyika. This study evaluated spatial variations in turbidity, total organic carbon (TOC), ammonium, nitrate, and phosphate in the treated effluent, the Kinyankonge River, mixing zones, and the river-lake confluence. Results revealed marked variations among sampling sites. Turbidity and phosphate concentrations were the highest at the wastewater outlet, whereas high ammonium and TOC concentrations were observed downstream. Nitrate concentrations remained high throughout the study area, indicating persistent nitrogen inputs. These findings suggest that treated wastewater and other environmental sources contribute to water quality changes within the Kinyankonge River system before its discharge into Lake Tanganyika. Continuous monitoring and integrated watershed management are essential to minimize nutrient enrichment and protect the ecological integrity of receiving aquatic ecosystems. Furthermore, nutrient recovery

strategies should be considered and implemented for their use in agriculture as green fertilizers.

Keywords: Wastewater treatment, Kinyankonge River, Lake Tanganyika, organic carbon, inorganic nutrients

Introduction

The rapid growth of urban populations and industrial activities has increased pressure on freshwater resources worldwide. Wastewater discharges represent one of the major sources of pollution affecting rivers, lakes and coastal ecosystems, particularly in developing countries where wastewater treatment infrastructure remains limited or operates under challenging conditions (Macedo et al., 2022). Untreated or insufficiently treated wastewater introduces substantial quantities of organic matter, suspended solids, nutrients and other contaminants into receiving environments, resulting in water quality deterioration and ecological degradation (Jing et al., 2024).

Wastewater treatment plants (WWTPs) play an essential role in reducing pollutant loads before effluents are released into natural water bodies. Through a combination of physical, chemical, and biological processes, these facilities are designed to decrease concentrations of suspended solids, organic matter and nutrients that may adversely affect aquatic ecosystems (Tchobanoglous et al., 2003). In many developing countries, stabilization pond systems remain among the most widely used wastewater treatment technologies because of their relatively low operational costs and adaptability to tropical climates (Ábrego-góngora et al., 2015). Nevertheless, treated effluents may still contain residual pollutants capable of influencing downstream water quality and aquatic ecosystem functioning.

In Burundi, the Buterere wastewater treatment plant (BWWTP) constitutes the principal municipal wastewater treatment facility serving the city of Bujumbura. The treatment system consists of a series of interconnected basins through which wastewater undergoes sequential physical and biological treatment processes. After preliminary removal of coarse materials and settleable solids, wastewater passes through biological treatment ponds where microbial communities promote the degradation of organic matter and the transformation of nutrients. During its progression through these basins, suspended particles are progressively removed through sedimentation, organic carbon is reduced through biological oxidation, and nitrogen and phosphorus compounds undergo various physicochemical and biological transformations(Tchobanoglous et al., 2003; Wissam S.AI-Rekabi, 2007). The final effluent is discharged into the Kinyankonge River, which subsequently flows into Lake Tanganyika.

Lake Tanganyika is one of the world's oldest, deepest, and most biodiverse freshwater ecosystems. The lake supports exceptional ecological richness, including numerous endemic fish, mollusk, crustacean, and algal species that contribute significantly to regional biodiversity and food security (Cohen et al., 1993). In addition to its ecological importance, Lake Tanganyika provides essential ecosystem services, including fisheries, transportation, domestic water supply and economic opportunities for millions of people living within its basin. Consequently, maintaining the quality of waters entering the lake is fundamental for preserving its ecological integrity and the livelihoods that depend upon it.

Among water quality indicators, nutrient concentrations are particularly important because they regulate biological productivity in freshwater ecosystems. Excessive inputs of phosphorus and nitrogen frequently stimulate eutrophication, leading to excessive algal growth, reduced water transparency, oxygen depletion, habitat degradation and loss of biodiversity (Camargo & Alonso, 2006). Phosphate is often considered the principal limiting nutrient in freshwater systems and its enrichment may profoundly alter aquatic community structure and ecosystem functioning. Similarly, elevated concentrations of nitrate and ammonium may disrupt nutrient cycling processes and contribute to ecological imbalance in receiving waters (Yu et al., 2017).

Organic matter represents another major environmental concern in wastewater-impacted ecosystems. TOC is widely recognized as an indicator used to assess the presence of dissolved and particulate organic matter in water. TOC in high concentrations may increase microbial activity and oxygen demand during decomposition processes, potentially reducing habitat suitability for sensitive aquatic organisms (Shannon et al., 2008). Furthermore, organic matter influences numerous biogeochemical processes and may facilitate the transport of contaminants within aquatic environments. The persistence of excessive organic carbon loads can therefore affect both water quality and ecological stability in rivers and lakes.

Turbidity is an equally important parameter because it reflects the concentration of suspended particles present in the water column. Turbidity reduces light penetration, limits photosynthetic activity, and may negatively affect primary productivity in aquatic ecosystems. Suspended sediments can also serve as carriers for nutrients, pollutants, and microorganisms, thereby amplifying water quality degradation. In Lake Tanganyika, increased sediment inputs have been associated with habitat alteration and reductions in biodiversity, particularly in littoral zones where many endemic species occur (Cohen et al., 1993). Previous investigations have demonstrated that rivers draining urbanized areas of Bujumbura can transport significant loads

of nutrients and suspended matter toward the lake, highlighting the importance of continuous monitoring (Yu et al., 2017).

Several studies have examined wastewater treatment efficiency and water quality degradation in different aquatic environments worldwide (Ábrego-góngora et al., 2015 ; Jing et al., 2024) and (Macedo et al., 2022). However, in Burundi, relatively limited information is available regarding the spatial distribution of nutrients, organic carbon and turbidity in waters receiving treated effluents from the Buterere Wastewater Treatment Plant. Previous investigations in the Kinyankonge River have reported evidence of nutrient enrichment and declining water quality downstream of urban areas(Niyongabo et al., 2021), emphasizing the need for continued environmental assessment.

Therefore, the present study aimed to evaluate the spatial variations of turbidity, phosphate, ammonium, nitrate and total organic carbon in the treated effluent released from the Buterere Wastewater Treatment Plant, the Kinyankonge River, and the confluence zone with Lake Tanganyika. By assessing the distribution of these key water quality parameters, the study sought to provide insight into the potential influence of treated wastewater and other environmental inputs on the ecological condition of receiving waters and to contribute to the sustainable management of aquatic ecosystems in Burundi.

Materials and Methods

Study area and Sampling sites

Water samples were collected from the BWWTP and from multiple points along the Kinyankonge River. The BWWTP receives municipal sewage from the city of Bujumbura, the economic capital of Burundi. Sampling locations were organized into four zones as shown in Figure 1:

a) zone 1: Wastewater treatment plant outlet
b) zone 2: Kinyankonge River
c) zone 3: Mixing zones where treated effluent from the BWWTP interacts with water from the Kinyankonge River.
d) Zone 4: the confluence of the Kinyankonge River and Lake Tanganyika



Figure 1: Map of the sampling zones

Sampling and analysis strategies

Water samples were collected on 29 July 2025 from all selected monitoring sites, including the wastewater treatment plant outlet, river sampling points, mixing zones and the river-lake confluence area. A single sampling campaign was conducted to evaluate the spatial variation of water quality parameters within the study area. At each sampling site, one representative water sample was collected using a sterilized bucket attached to a rope and transferred into clean polyethylene bottles. The samples were preserved under cooled conditions and transported to the chemical and environmental analysis laboratory of the University of Burundi for analysis according to standard preservation procedures. All physicochemical determinations were performed in triplicate, and the values reported in this study correspond to the arithmetic mean of the three analytical measurements. The selected sampling locations were intended to represent the treated effluent, the receiving river system, the effluent-river mixing zones and the point where the Kinyankonge River enters Lake Tanganyika.

Measurement of turbidity

Turbidity was measured using a portable turbidimeter (HACH 2100Q IS), following standard protocols.

Total organic carbon determination

Total organic carbon was estimated using a potassium permanganate oxidation method adapted from classical wet-chemical procedures for organic matter assessment. A 50 mL water sample was acidified with sulfuric acid (H_2SO_4, 1:1) and reacted with a known excess of potassium permanganate ($KMnO_4$, 0.01 M). The mixture was heated at 90–100°C for 30 minutes to promote oxidation of organic compounds. After cooling, the residual $KMnO_4$ was determined by titration with a standardized sodium oxalate solution. A blank containing distilled water and reagents was analyzed following the same procedure. The amount of oxidant consumed by the sample was calculated from the difference between the blank and sample titration volumes. The corresponding carbon concentration was calculated stoichiometrically and expressed as mg of C/ L.

Nutrients analysis

A multiparameter photometer (HI83399, Hanna Instruments) was used for colorimetric determination of ammonium (Nessler method), phosphate (ascorbic acid method), and nitrate (cadmium reduction method). All analyses followed standard methods (APHA, AWWA, WEF (2017))

Study limitations

This study was based on a single sampling campaign conducted during the dry season and therefore provides a snapshot of water quality conditions at the time of sampling. Seasonal variations and temporal fluctuations were not assessed. Consequently, the results should be interpreted as representing spatial differences among sampling locations rather than long-term trends in water quality.

Results and Discussion

Turbidity (NTU) evaluation

The turbidity results showed substantial spatial variation among sampling sites (Figure 2). The highest turbidity value was recorded at the wastewater treatment plant outlet (220 NTU), indicating a high concentration of suspended particles. In contrast, considerably lower values were observed at the riverine and mixing sites, ranging from 13.3 NTU in the Kinyankonge River (zone 2) to 41.9 NTU at the confluence zone between the Kinyankonge River and Lake Tanganyika (zone 4). These results indicate a

progressive reduction in suspended matter after discharge into the receiving environment.

The marked decrease in turbidity observed between the outlet and downstream stations may be attributed to dilution processes, sedimentation of suspended particles, and hydrodynamic mixing within the river system. Similar observations have been reported in urban rivers where wastewater discharges become progressively diluted by natural water flows, leading to reduced concentrations of suspended solids downstream (Yu et al., 2017). Furthermore, the relatively low turbidity measured within the river channel suggests that the receiving waters possess some capacity to attenuate particulate inputs through natural settling processes.

However, turbidity values increased again at several mixing zones and reached the highest downstream value at the river-lake confluence (41.9 NTU). This pattern may reflect the resuspension of bottom sediments, inputs from surrounding urban runoff, or the accumulation of suspended materials transported from upstream sections of the watershed. Similar increases in turbidity near river mouths and lake interfaces have been associated with complex hydrological interactions and sediment transport dynamics (Cohen et al., 1993).

High turbidity values can significantly influence aquatic ecosystems by reducing light penetration and consequently limiting photosynthetic activity and altering habitat conditions for aquatic organisms. High suspended solid concentrations may also facilitate the transport of nutrients, organic matter, and contaminants, thereby contributing to the degradation of water quality (Jing et al., 2024). Given that Lake Tanganyika is a biodiversity hotspot and an important freshwater resource, the persistence of moderate turbidity levels at the confluence highlights the need for continuous monitoring of particulate pollution entering the lake.

Overall, the observed turbidity gradients suggest that although natural river processes contribute to reducing suspended matter concentrations, downstream turbidity increases indicate that additional sources of particulate pollution continue to affect the Kinyankonge River system before its discharge into Lake Tanganyika.

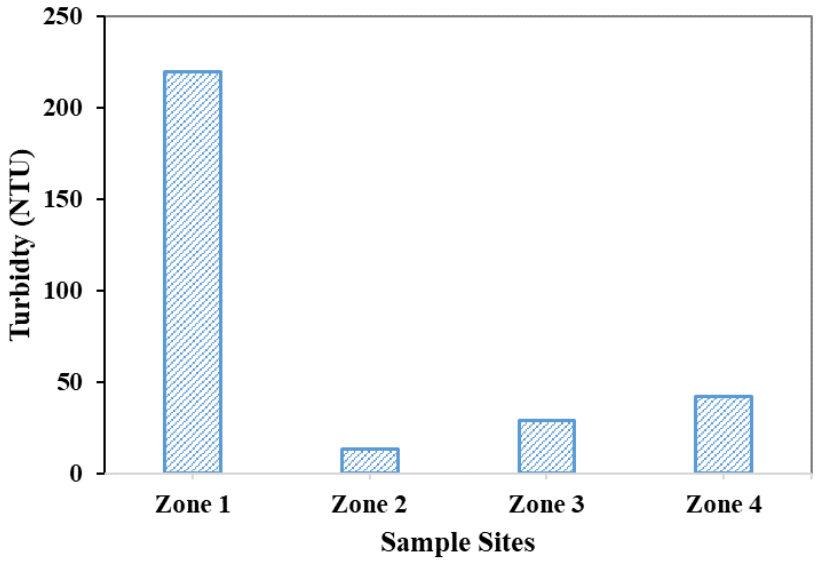


Figure 2: Turbidity profile across sampling zones

Phosphates (mg/L)

Phosphate concentrations exhibited considerable spatial variations across the sampling zones (Figure 3), ranging from 3.0 mg/L in the Kinyankonge River to 21.5 mg/L at the wastewater treatment plant outlet. Elevated phosphate concentrations at the outlet indicate that the treated effluent remains a significant source of phosphate entering the receiving environment. Although phosphate concentrations were lower in the river and mixing zones, values remained sufficiently high to contribute to nutrient enrichment of downstream waters.

Its persistence in surface waters is of environmental concern because phosphates are frequently the limiting nutrient for algal growth in freshwater ecosystems. Increased phosphate availability can stimulate excessive primary productivity and contribute to eutrophication processes, thereby affecting water quality and aquatic biodiversity. Similar observations have been reported in wastewater-impacted aquatic systems where phosphate enrichment altered ecosystem functioning and nutrient dynamics (Camargo & Alonso, 2006).

The increase in phosphate concentration observed at the confluence between the Kinyankonge River and Lake Tanganyika may indicate additional phosphate inputs from surrounding human activities, sediment interactions, or diffuse runoff sources. Consequently, continuous monitoring of phosphate concentrations remains important for protecting the ecological integrity of the Kinyankonge River and limiting nutrient loading into Lake Tanganyika (Qian et al., 2026).

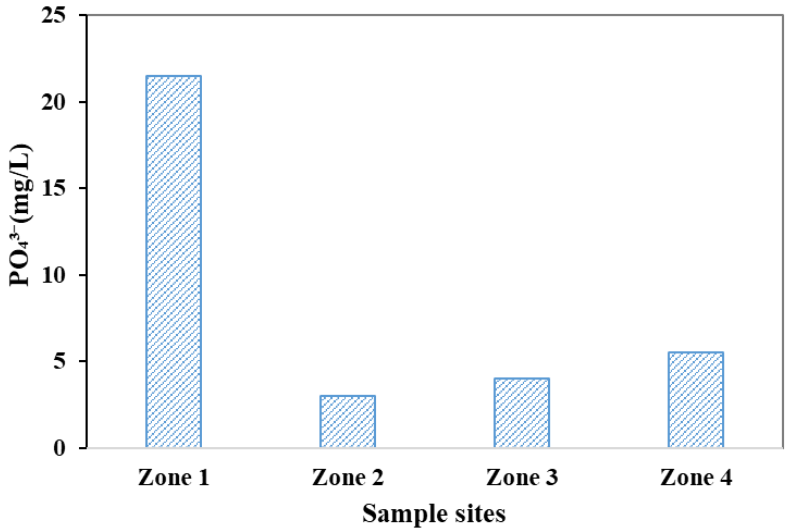


Figure 3: Phosphate concentration profile across sampling zones

Nitrogen Ammonia

Ammonium concentrations varied markedly among sampling zones, with the lowest concentration measured at the wastewater treatment plant outlet (0.7 mg/L) and markedly higher concentrations recorded within the river and mixing zones, reaching 21 mg/L at zone 3 (Figure 4). These observations suggest that additional ammonium sources may exist within the receiving environment downstream of the effluent discharge point.

The observed high concentrations of ammonium in the river system may be associated with various anthropogenic activities occurring within the watershed, including domestic wastewater discharges, runoff from surrounding settlements, and decomposition of organic matter. Similar increases in ammonium concentrations downstream of wastewater discharge points have been reported in urban aquatic systems exposed to multiple nutrient sources (Jing et al., 2024) and in tropical treatment plants where aeration or microbial community balance was insufficient (Wissam S.AI-Rekabi, 2007). The observed spatial variability highlights the need for further investigations to identify the relative contribution of wastewater discharge, runoff, and other anthropogenic activities to ammonium contamination in the watershed.

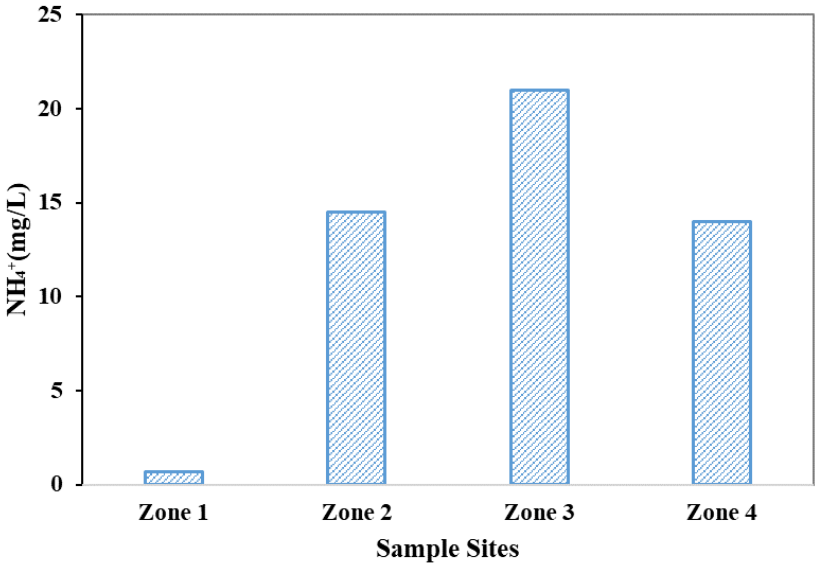


Figure 4: Ammonium concentration profile across sampling zones

Nitrates

Nitrate concentrations remained at a high level throughout the study area, varying from 40 mg/L at the river-lake confluence to 68 mg/L at the wastewater treatment plant outlet (Figure 5). The persistence of relatively high nitrate concentrations across all sampling zones indicates continuous nitrogen inputs affecting the river system.

The gradual decrease in nitrate concentrations observed from the outlet towards Lake Tanganyika may be related to dilution processes, biological uptake by aquatic organisms, or interactions with sediments. Similar spatial patterns have been described in wastewater-influenced rivers where nutrient concentrations progressively decline downstream because of natural attenuation processes (Camargo & Alonso, 2006)

Nevertheless, nitrate concentrations remained substantial throughout the monitoring area, suggesting that nitrogen loading continues to influence water quality. Nitrate in high concentrations are of concern because they may contribute to eutrophication and ecological disturbances in receiving waters (Kadlec, 2008) (Macedo et al., 2022). Continuous monitoring is required to better understand nitrogen dynamics and identify the contribution of both treated effluent and other environmental sources to nitrate concentrations in the receiving waters.

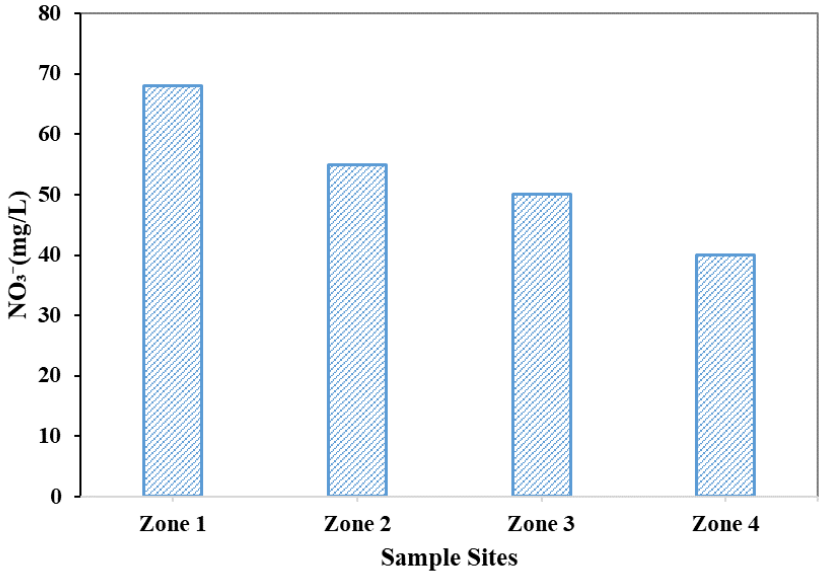


Figure 5: Nitrate concentration profile across sampling zones

TOC

TOC concentrations ranged from 26.12 to 31.23 mg/L in Zones 1 to 3 before increasing markedly to 54.35 mg/L at the confluence with Lake Tanganyika. This pattern suggests the influence of additional organic matter sources within the watershed and downstream environments. The increase may be associated with additional organic matter inputs from upstream activities, sediment interactions, or other environmental sources.

Similar downstream increases have been reported in distribution systems where biofilm release reintroduces organic carbon (Servais et al., 1995). High level of TOC in water is problematic because it sustains bacterial growth and increases oxygen demand, thereby destabilizing aquatic ecosystems (Shannon et al., 2008) and (Ábrego-góngora et al., 2015). Continuous monitoring is therefore essential to better understand the sources and dynamics of organic carbon within the receiving aquatic environment.

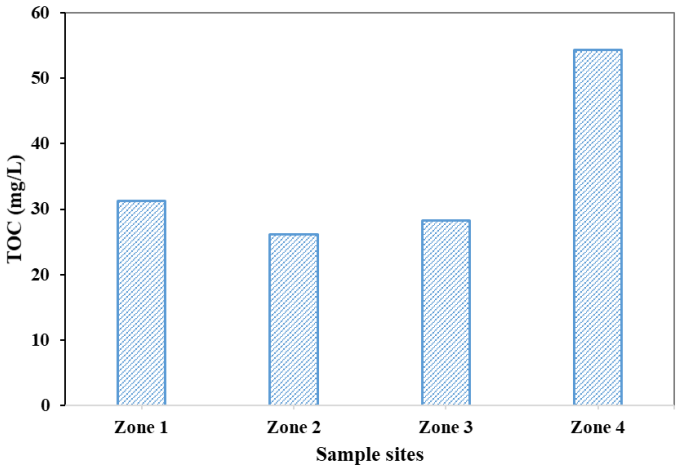


Figure 6: Total organic carbon concentration profile across sampling zones

Conclusions

This study assessed the spatial distribution of turbidity, phosphate, ammonium, nitrate and total organic carbon in the treated effluent discharged from the Buterere wastewater treatment plant, the Kinyankonge River, and the confluence zone with Lake Tanganyika. Significant variations in water quality parameters were observed among sampling zones, indicating the influence of treated effluent discharge and additional environmental pollution sources within the watershed. High levels of nutrients and organic carbon concentrations at several downstream locations suggest continued pressure on the receiving aquatic environment. Such conditions may contribute to nutrient enrichment, increased organic loading and degradation of aquatic ecosystem health. These findings highlight the importance of continuous water quality monitoring and integrated watershed management strategies aimed at protecting the ecological integrity of the Kinyankonge River and Lake Tanganyika. Future studies should incorporate seasonal investigations and influent wastewater characterization to better understand pollutant dynamics and treatment efficiency. Moreover, strategies for nutrient recovery should be considered in order to use them in agriculture to improve crop growth and yield rather than causing risks to receiving water body ecosystems.

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References:

1. Ábrego-góngora, C. J., Briones-gallardo, R., Bernal-jácome, L. A., Escalas-cañellas, A., Multidisciplinario, P., Posgrado, D., Ambientales, C., Autónoma, U., & Luis, D. S. (2015). Evaluation of Three Dynamic Models for Aerated Facultative Lagoons. *Journal of Water Resource and Protection*, *7*(September), 1131–1142.
2. Camargo, J. A., & Alonso, Á. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems : A global assessment. *Environment International*, *32*, 831–849. https://doi.org/10.1016/j.envint.2006.05.002
3. Cohen, A. S., Bills, R., Cocquyt, C. Z., & Caljon, A. G. (1993). The Impact of Sediment Pollution on Biodiversity in Lake Tanganyika. *Conservation Biology*, *7*(3), 667–677. https://doi.org/10.1046/j.1523-1739.1993.07030667.x
4. Jing, W., Sajnani, S., Zhou, M., Zhu, H., & Xu, Y. (2024). Evaluating the Ecological Impact of Wastewater Discharges on Microbial and Contaminant Dynamics in Rivers. *Water*, 1–15.
5. Kadlec, R. H. (2008). Comparison of free water and horizontal subsurface treatment wetlands. *Ecological Engineering*, *5*, 159–174. https://doi.org/10.1016/j.ecoleng.2008.04.008
6. Karaa, K., Karam, F., Tarabey, N., & Guelloubi, R. (2005). WASTEWATER TREATMENT AND REUSE IN LEBANON : KEY FACTORS FOR FUTURE AGRICULTURAL USES.

CIHEAM, *225*, 215–225.
7. Macedo, H. E., Lehner, B., Nicell, J., Grill, G., Li, J., & Limtong, A. (2022). Distribution and characteristics of wastewater treatment plants within the global river network. *Earth Syst. Sci. Data*, *1*, 559–577.
8. American Public Health Association (APHA), American Water Works Association (AWWA), & Water Environment Federation (WEF). (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). APHA.
9. Niyongabo, A., Niyokindi, L., & Hatungimana, P. (2021). Evaluation of the water quality of sewage treatment plant effluents (SETREP) and its effects on water quality in the Kinyankonge River in Burundi. *Journal of Applied Biosciences*, *162*, 16744–16753.
10. Qian, Q., Qin, K., Sun, X., Chu, Y., Li, Z., Wang, J., Liu, X., & Tan, Z. (2026). Product-Oriented Phosphorus Recovery from Wastewater and Waste Streams : Sources , High-Value Products , Technologies , and Techno-Economic Assessment. *Sustainability*, 1–26.
11. Servais, P., Laurent, P., & Randont, G. (1995). *Comparison of the bacterial dynamics in various French distribution systems*. *44*(l), 10–17.
12. Shannon, M. A., Bohn, P. W., Elimelech, M., Georgiadis, J. G., Marin, B. J., & Mayes, A. M. (2008). Science and technology for water purification in the coming decades. *Nature*, *452*(March), 301–310. https://doi.org/10.1038/nature06599
13. Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). *Wastewater engineering: Treatment and reuse* (4th ed.). McGraw-Hill.
14. Wissam S.AI-Rekabi, H. Q. and W. W. Q. (2007). *Improvements-in-Wastewater-Treatment-Technology.pdf* (pp. 104–110).
15. Yu, C., Chen, S. S., Zhang, L., Gao, Q., Wang, Z., & Shen, Q. (2018). Changes in water quality of the rivers discharging into Lake Tanganyika in Bujumbura, Burundi. *Aquatic Ecosystem Health & Management*, *21*(2), 201-212. https://doi.org/10.1080/14634988.2017.1394772