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Approaches to Mitigating Environmental Impacts in Buffer Basins Used as Ornamental Lakes: A Case Study in an Urban Residential Condominium

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Abstract

This study evaluates the effectiveness of bioremediation in improving water quality in urban buffer basins converted into ornamental lakes. With the growing problem of water pollution in urbanized areas, a methodolo-gy is proposed that includes filters and the application of bioaugmented microorganisms to mitigate contamination. The case study focuses on an artificial lake in an urban condominium, examining the metabolic processes of bioremedi-ation under aerobic and anaerobic conditions and their effects on the degradation of pollutants. The results show a significant improvement in water quality, with a reduction in turbidity and concentration of pollutants, in addition to the unexpected formation of quaternary ammonia, a byproduct with potential environmental implications. This finding highlights the importance of rigorous monitoring of bioremediation processes. The study emphasizes the potential of nature-based solutions to solve urban environmental problems, promoting sustainability and resilience in cities. The research contributes to the development of innovative practices in water resources management, encouraging the adop-tion of simple and adaptive approaches that integrate scientific knowledge, community involvement and public poli-cies.

Keywords: Effective Microorganisms (EM); Bioremediation; Urban Sustainability

Abbreviations: EM: Effective Microorganisms; MNR: Monitored Natural Revitalization; STP's: Sewage Treatment Plants

Introduction

The coast of the state of Rio de Janeiro is an area of global prominence for its ecological diversity, economic im-portance and social relevance. Home to an extensive variety of ecosystems, including sandy beaches, lush mangroves and coral reefs, this region supports impressive biodiversity Silva [1]. These environments are fundamental for the survival of countless species of flora and fauna, many of which are endemic and play critical ecological roles Oliveira [2]. Furthermore, these coastal areas are the basis for vital economic activities, such as fishing, which provides a livelihood for thousands of families, and tourism, which attracts millions of visitors annually, con-tributing significantly to the local and national economy Santos [3].

However, the growing rampant urbanization in recent decades, combined with the lack of adequate infrastructure for sewage treatment, has generated a worrying increase in coastal pollution. It is estimated that more than 70% of the sewage generated in the region is dumped without adequate treatment, carrying large amounts of nutrients, pathogens and chemical pollutants to coastal water bodies Ferreira [4]. This untreated sewage causes eutrophication processes, where excess nutrients lead to the uncontrolled growth of algae, resulting in a decrease in dissolved oxygen levels in the water and causing the death of fish and other aquatic organisms Silva [1]. The degradation of water quality also directly affects public health, increasing the incidence of waterborne diseases, such as gastroenteritis and hepatitis Ferreira [4].

In addition to the impacts on biodiversity and human health, coastal pollution compromises the quality of ecosys-tem services offered by these environments, such as protection against storms and the maintenance of water quality Oliveira [2]. The loss of marine biodiversity, exacerbated by the degradation of natural habitats, has signifi-cant economic consequences, especially for communities that depend on fishing and tourism Santos [3]. The decrease in the tourist attractiveness of beaches and the reduction in fishing catches not only affect the local economy, but also have repercussions on a national scale, given the strategic importance of the Rio de Janeiro coastline for Brazil Silva [1]. In summary, the combination of urban pressures and the absence of effective public policies for waste management and conservation of coastal ecosystems is putting one of the country's most valuable natural heritage at risk. To mitigate these impacts, it is imperative to adopt sustainable solutions, integrating environmental preservation with the socioec-onomic development of the region Silva [1]; Oliveira [2].

Literary Review

Coastal Pollution and its Impacts

Coastal pollution on the coast of Rio de Janeiro is a multifaceted problem, resulting mainly from the release of untreated sewage into coastal waters. This sewage introduces a range of contaminants, including nutrients such as nitro-gen and phosphorus, heavy metals and pathogens, which can trigger eutrophication processes. Eutrophication leads to excessive growth of algae, reducing oxygen levels in the water and causing the death of fish and other aquatic organ-isms Silva [1]. Furthermore, the presence of pathogens in untreated sewage is associated with an increase in several waterborne diseases, negatively impacting public health Ferreira [4].

Impacts on Marine Biodiversity

Marine biodiversity is particularly vulnerable to pollution from untreated sewage. Fish, mollusks, and coral species suffer from habitat degradation, which can lead to mass mortality and changes in the composition of biological com-munities Oliveira [2]. Biodiversity loss not only affects marine ecosystems but also has significant economic consequences for coastal communities that depend on fishing and tourism. The quality of beaches and recreational wa-ters is directly impacted, reducing tourist appeal and, consequently, the income generated by this activity Santos [3].

Drainage, Sewage Treatment and Public Policies

The water reality, especially in aspects related to water supply and use, is a topic that, historically, has marked discussions about regions with low rainfall. These concerns have been focused on in studies in recent years and re-searchers' efforts have focused on trying to understand the correlation between water in these regions and their socioec-onomic indicators. Water scarcity seriously affects the population, generating misery, resulting from the loss of produc-tive capacity as a result of environmental degradation Paz [5]; Cunha [6]. Accelerated urbanization has been a global phenomenon in recent decades, resulting in the transformation of green areas into built urban environments Guitarra [7]. In this context, adequate management of water resources be-comes crucial, especially considering the challenges related to rainwater drainage and water quality in urban water bodies Rocha [8]. One of the strategies commonly used to deal with these challenges is the construction of buffer basins, which aim to control water flow and reduce the impacts of flooding in urban areas.

This urban expansion has led to a series of negative consequences, including recurrent flooding, especially due to climate change and the lack of adequate drainage infrastructure, as well as the limited capacity of public enforcement authorities Rocha [8] and Höltz [9]. Furthermore, urbanization has contributed to the pollution of water bodies, compromising their natural, recreational and economic values. Under these conditions, the implementation of drainage systems with buffer basins emerged as a strategy to miti-gate the impacts of urban waterproofing in micro-basins. These systems aim to control both the flow and the quality of rainwater, which, when flowing over impermeable surfaces, carries with it a variety of pollutants, many of which are associated with suspended sediments Gribbin [10].

Given this scenario, human intervention becomes crucial to restore the lost environmental balance. Various restora-tion methods have been explored, varying in terms of the scale of intervention in the natural environment and the stabil-ity of its parameters (SØNDERGAARD et al., 2007). In this context, microbiological bioremediation emerges as a prom-ising approach for the remediation of degraded areas, involving the application of consortia of microorganisms and their biochemical compounds to accelerate the degradation of pollutants Mingjun [11]. To mitigate these impacts, it is essential to implement effective sewage treatment technologies and develop strict public policies. Biological and physical-chemical treatment systems can significantly reduce the load of pollutants, while stricter laws and adequate supervision guarantee the protection of coastal ecosystems Pereira [12]. Furthermore, environmental education and public awareness are fundamental to promoting sustainable practices and encouraging community participation in environmental conservation Costa [13].

Bioremediation as a Solution

Microbiological bioremediation emerges as a promising approach for the remediation of degraded areas, involving the application of consortia of microorganisms and their biochemical compounds to accelerate the degradation of pol-lutants Mingjun [11]. Among the microorganisms with bioremediation potential, lactic acid bacteria, yeast and Bacillus stand out, which are known for their ability to degrade a variety of organic and inorganic compounds. In this context, it is proposed to introduce these

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microorganisms into buffer basins converted into ornamental lakes, aim-ing to accelerate the biodegradation of organic matter and reduce the environmental impacts caused by waste transported by the urban drainage network.

Bioremediation

Bioremediation is a process that employs living organisms, mainly microorganisms, to remove or neutralize con-taminants from the environment. This method is based on the ability of microorganisms to degrade, transform or ac-cumulate toxic substances present in soil and water. The enzymes produced by these microorganism's function as bio-catalysts, facilitating the conversion of pollutants into less toxic or harmless compounds. (Saleen et al, 2021; Saxena et al, 2020; Abatenh [14]; Ahirwar et al, 2016). In the environmental context, bioremediation stands out as an innovative and essential biological technique for converting polluting waste into water and soil, resulting in substances that can be biologically reused (Mallmann et al, 2019). This mechanism is increasingly relevant in the face of contemporary challenges generated by the environmen-tal impacts of human activities. Microorganisms, protagonists of this process, demonstrate a remarkable ability to sur-vive in extreme conditions, driven by robust metabolic activity that enables them to adapt to diverse environmental sce-narios. This metabolic versatility, together with a wide nutritional range, makes them crucial agents in the bioremedia-tion of environmental pollutants, allowing the detoxification and revitalization of contaminated environments by transforming hazardous waste into less harmful components Abatenh [14]; Saleen et al, 2021; Saxena et al, 2020; Ahirwar et al, 2016).

Principles and Mechanisms

The microorganisms used in bioremediation, such as bacteria, fungi, yeast and algae, act as biocatalysts, facilitat-ing biochemical reactions that degrade pollutants. Metabolic reactions are mediated by enzymes that belong to the groups of oxidoreductases, hydrolases, lyases, transferases, isomerases and ligases. Each group of enzymes plays a crucial role in the biochemical reactions involved in bioremediation. The combination of these enzymes allows micro-organisms to degrade and transform a wide range of environmental pollutants, converting them into less toxic or harm-less substances. This diverse enzymatic process is essential for the efficiency and effectiveness of bioremediation in dif-ferent contaminated environments (Saleen et al, 2021; Hasan et al, 2006; Gaylarde et al 2005).

Bioremediation Techniques

Bioremediation can be carried out through two main methods: in situ and ex situ. In the in-situ method, decon-tamination occurs directly at the affected site, avoiding the need to move contaminated soil or water (Saleen et al, 2021). An example of this method is the application of bioremediation techniques to oil spills directly in the impacted environment. In contrast, the ex-situ method involves removing contaminated materials from their original location to be treated in specific facilities, such as bioreactors or treatment tanks, allowing for more rigorous control of treatment conditions (Saleen et al, 2021; Abatenh [14]; Gaylarde et al 2005).

Biostimulation

When consulting the literature, biostimulation consists of the addition of nutrients or other substances to stimulate the growth and activity of microorganisms already present in the contaminated environment. According to the work of Smith J [15], the objective is to optimize environmental conditions so that microorganisms can degrade pollu-tants more efficiently. Biostimulation can be applied both in situ and ex situ (Saleen et al, 2021; Abatenh [14]; Gaylarde et al 2005). And according to the aforementioned authors, the components frequently added during bi-ostimulation include:

a) Nutrients: Essential elements such as nitrogen, phosphorus and potassium are added to promote microbial growth.

b) Additional substrates: Compounds that serve as carbon or energy sources for microorganisms.

c) pH adjustments: Changes in the pH of soil or water to create a more favorable environment for microbial activ-ity.

When observing the analyzes of these authors, biostimulation is particularly effective in environments where the necessary microorganisms are already present, but in insufficient numbers or in conditions close to ideal for the degra-dation of pollutants. In other words, in an environment where it is possible to control the variables for biostimulation to occur (Saleen et al, 2021; Abatenh [14]; Smith [15]; Gaylarde et al 2005).

Bioaugmentation

Continuing with the analysis of the aforementioned works, bioaugmentation consists of the introduction of specific microorganisms into the contaminated environment with the aim of intensifying and accelerating the bioremediation process. These microorganisms can be natural, genetically modified strains or microbial consortia (mixtures of different species) that have specific metabolic capabilities to degrade certain contaminants (Saleen et al, 2021; De Frias et al 2020; Abatenh [14]; Smith [15]; Gaylarde et al. 2005). Bioaugmentation is applicable when:

a) Native microorganisms are insufficient: When the local microbial population is not able to degrade contami-nants effectively.

b) Contaminants are difficult to degrade: When contaminants require microorganisms with specific metabolic capabilities

Analyzing the work of these authors, bioaugmentation can be combined with biostimulation to create an optimized environment

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in terms of microbial population and environmental conditions.

Advantages and Disadvantages

Each technique has advantages and disadvantages, depending on the type of contaminant, the location of contam-ination and environmental conditions:

a) Bioremediation: It is generally economical and environmentally friendly but can be slow and limited by the availability of effective microorganisms and environmental conditions.

b) Biostimulation: It can be a quick and relatively inexpensive approach to improving bioremediation, but it depends on the presence of native microorganisms capable of degrading contaminants.

c) Bioaugmentation: Can be very effective in treating specific and resistant contaminants but can be expensive and requires detailed knowledge of the microorganisms and the environment.

The combination of these techniques offers an integrated and effective approach to the remediation of contaminated environments, maximizing the efficiency of pollutant degradation and minimizing environmental and economic im-pacts. Playing crucial roles in the degradation, eradication, immobilization or transformation of a wide range of con-taminants, converting them into enzymatic by-products that are reintegrated into the food chain, becoming accessible for consumption by other forms of life (Wróbel et al, 2023; Gaylarde et al 2005). This distinctive capability posi-tions bioremediation techniques as an extremely effective resource in mitigating environmental problems, providing a more sustainable and economically efficient alternative compared to conventional remediation meth-ods (Søndergaard; Jeppesen, 2007).

Specifically, the Monitored Natural Revitalization (RNM) method illustrates the long-term commitment to ecologi-cal revitalization, seeking the biological rebalancing of affected ecosystems. This approach is based on the understand-ing that, by reintegrating natural processes and promoting the transformation of contaminants into less toxic substanc-es, it is possible to stimulate natural regeneration and protect both human health and biodiversity. The effectiveness of the RNM is assessed through a series of indicators, such as the burial of contaminants, the stability of sediments, and the natural transformation and attenuation of pollutants, providing a comprehensive picture of environmental revitali-zation, (Infographic 1) Magar e Wenning [16].

Within the spectrum of bioremediation agents, microorganisms of the genus Bacillus spp. and Lactobacillus spp. are often highlighted due to their remarkable ability to decompose a wide variety of harmful compounds Hlordzi [17]; MA [18]. These organisms have been the subject of extensive research and have been successfully applied in various contamination scenarios, proving to be effective instruments in revitalizing surface and underground waters, revitalizing polluted soils and treating industrial effluents. The ability of these bacteria to process contaminants, from heavy metals to complex organic compounds, under different environmental conditions highlights the vast potential of microbial bioremediation Wróbel et al, 2023; Hlordzi [17]; MA [18].

The execution of bioremediation, especially when mediated by microorganisms such as Bacillus spp. and Lactobacil-lus spp., reveals a promising and sustainable methodology for treating pollution. This process, supported by an in-depth understanding of the metabolic mechanisms involved, which can range from aerobic to anaerobic activities, opens new avenues for environmental decontamination. Furthermore, bioremediation extends beyond mere metabolic degradation, encompassing techniques such as biosorption, bioaccumulation and bioprecipitation, which expand the scope of action of microorganisms in capturing and transforming pollutants (Perelo, 2010; Saxena et al 2020; Gaylarde et al 2005).

Bioremediation Metabolic Processes

The metabolic processes involved in microbiological bioremediation can occur under aerobic or anaerobic condi-tions, depending on the availability of oxygen in the contaminated environment Chernicharo [19]. In the pres-ence of oxygen, aerobic degradation of contaminants occurs, where microorganisms use oxygen to oxidize organic compounds, producing carbon dioxide, water and biomass as byproducts. In the absence of oxygen, microorganisms can carry out anaerobic degradation of contaminants, using other mechanisms, such as nitrate, sulfate or carbon diox-ide, as final electron acceptors, as exemplified in (Infographic 1) Chernicharo [19].

Natural Revitalization Monitoring

For the control and evaluation of bioremediation, the Monitored Natural Revitalization (MNR) method, (Infographic 2), will be used, which illustrates the long-term commitment to ecological recovery, seeking the biological rebalancing of affected ecosystems. This approach is based on the understanding that, by reintegrating natural processes and promot-ing the transformation of contaminants into less toxic substances, it is possible to stimulate natural regeneration and protect both human health and biodiversity. The effectiveness of the MNR is assessed through a series of indicators, providing a comprehensive picture of environmental recovery Magar & Wenning [16]. Pollution caused by untreated sewage on the coast of Rio de Janeiro represents a multifaceted challenge that re-quires an integrated and holistic approach. Effective mitigation strategies must combine technological advances, robust public policies and environmental education initiatives. Only through coordinated efforts will it be possible to protect these important coastal ecosystems and guarantee the environmental and economic sustainability of the region Al-Meida [20].

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Materials and Methods

The study area was a buffer basin transformed into an ornamental lake in an urban residential condominium, with an area of approximately 3,350 m^2 and an average volume of 1,675 m^3 (Figure 1) and is fed by rainwater from the con-dominium's drainage, without a source natural, with an outlet to the Arroio Fundo water body, only when it rains. To assist in bioremediation, a sequence of filters (ETA) with various particle sizes was constructed, going from coarser to finer (Figure 2). ETA aims to maintain water quality and apply bioinput to the artificial lake. To this end, an operational protocol was drawn up.

Figure 1: Aerial view of the Lake, Google Earth 2024.

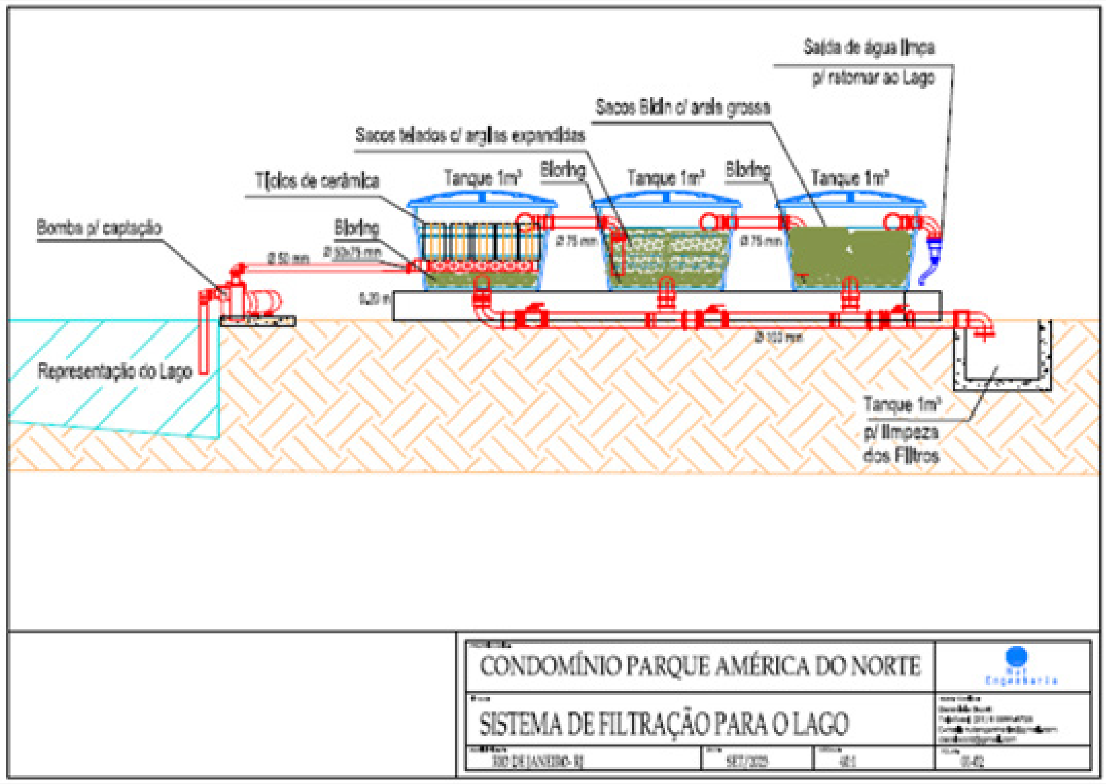

Figure 2: Assembly diagram of the Water Treatment Plant (ETA).

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The microorganisms selected for bioremediation were acquired in a commercial product that contained the species Lactobacillus plantarum in consortium with Saccharomyces cerevisiae in its formulation. The microorganisms were bioaugmented following the proportion of 5% inoculum, 1.5% activator, 0.4% salt and 95% clean, chlorine-free water. The product, after homogenization, grew for 3 days and, after the bioaugmentation time, was inoculated at the ETA. Water from the lake is captured and passes through the ETA to remove solids, coming into contact with microorganisms that will speed up the treatment. The application of bioaugmented microorganisms increased the efficiency of the ETA in reducing the pollutant load and improving the water quality of the ornamental lake. The use of these bioremediation techniques has shown to be a promising approach to address the challenges faced in the management of urban water bodies, especially in-built environments.

Results

The MNR results, detailed in Table 1 and illustrated in Figure 3, show a substantial improvement in the water quality of the ornamental lake after the application of bioremediation techniques. A significant reduction in levels of organic and inorganic pollutants was observed, as well as a decrease in turbidity. This improved water clarity reflects the effectiveness of the interventions carried out. These advances are in line with findings in the scientific literature that consistently highlight the effectiveness of bioremediation techniques in aquatic environments. Studies such as those by Smith [15] confirm that bioreme-diation not only effectively reduces the concentration of pollutants, but also improves the general quality of water in various aquatic contexts, highlighting its potential as a sustainable solution for the management of urban water re-sources. For the detailed analysis of the physical-chemical quality of the water before and after the bioremediation treatment, the Akso brand Micro 20 Multiparameter Photometer was used, as illustrated in Figure 4. This modern equipment ena-bles the precise analysis of multiple physical-chemical parameters. chemicals using just 4 ml of water sample per test. The analysis process involves the addition of specific reagent strips for each parameter, which makes it easier to obtain quick and reliable results. The accuracy of this advanced technology is critical for monitoring the effectiveness of biore-mediation interventions, providing essential data for environmental assessments and supporting management deci-sions.

Table 1: result of quality analysis, E = +/- 4.8ppm.

Indices	Before treatment	After treatment
Temperature (°C)	27.7	29.6
pH	9.6	9.6
DO - Dissolved Oxygen (mg/L)	2.8	6:50 AM
NH - -Ammonia (ppm)	0.44	0.1
qA-QACs – Quaternary Ammonium Compound (ppm)	0	9:50 AM
NO_2 - Nitrite (ppm)	0.08	0
NO_3 - Nitrate (ppm)	0	0
PO_4 - Phosphate (ppm)	0	0
S - Sulfide (ppm)	0.13	0
SO_4 - Sulfate (ppm)	0	0
TR1 - Turbidity (NTU)	17	0

(a) Before – 11/23/2023

(b) After – 03/10/2024

Figure 3: In these photos you can see the improvement in water quality before (a) and after (b) the WTP treatment enriched with Microorganisms.

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Figure 4: In these photos (a), (b), (c) and (d), it shows how the MNR was carried out.

Discussion

Evaluation and Improvements in the Bioremediation Process

The Multiparameter Photometer has been fundamental in simplifying data collection and analysis, ensuring the necessary precision to evaluate changes in the physicochemical composition of lake water. By comparing pre- and post-treatment data, we were able to quantify the impact of bioremediation on several parameters, including the signifi-cant reduction of nitrogenous compounds, phosphates and other pollutants. The consistency of these results with pre-vious studies Smith [15] reinforces the effectiveness of bioremediation techniques and increases the importance of continuous monitoring to ensure the ecological health of aquatic ecosystems. This rigorous monitoring is crucial to understanding ecosystem dynamics and planning future management and conservation actions. The drastic reduction in turbidity, from 17 NTU to 0 NTU, highlights a notable improvement in water transparency, fundamental to the health of the aquatic ecosystem. Turbidity is a key indicator of water quality, as high values indicate high concentrations of suspended particles that can be harmful to aquatic life. Effectively removing turbidity improves light penetration, favoring photosynthetic processes and, therefore, ecological balance.

Furthermore, a significant decrease in ammonia concentration was observed, from 0.44 ppm to 0.10 ppm, a crucial result given the toxicity of ammonia to aquatic life. The absence of post-treatment nitrite indicates the efficiency of the bioremediation system in converting nitrites, which are toxic, into less harmful forms, through the processes of nitrifica-tion and denitrification. The increase in dissolved oxygen from 2.80 mg/L to 6.50 mg/L also reflects the success of bioremediation, as ade-quate levels of dissolved oxygen are essential for the respiration of aquatic organisms. This increase is attributed to the reduction in the biochemical demand for oxygen necessary to decompose pollutants previously present.

To ensure the long-term management and sustainability of these interventions, an integrated approach involving continuous monitoring, community participation and effective public policies is essential. This holistic approach not only promotes immediate improvement in water quality, but also ensures the maintenance of the ecological health of aquatic ecosystems in the long term. The presence of quaternary ammonia (qA-CAQ) was detected at a concentration of 9.50 ppm at the ETA outlet after the bioremediation process, which raises the suspicion that the compound may be originated by the metabolism of the microorganisms used. This hypothesis suggests the need to expand studies to better understand the biochemical inter-actions involved and the detection challenges that arise in treatment.

Lactobacillus plantarum and Saccharomyces cerevisiae, used in bioremediation, are known to generate a variety of metabolites during their metabolic processes. Among these metabolites, organic acids and antimicrobial peptides stand out for their properties that can interfere with chemical detection, especially in systems based on colorimetric reactions, such as Akso's Micro 20 Multiparameter Photometer. These systems may confuse the changes in color or turbidity caused by such metabolites with the presence of quaternary ammonium, as described in previous studies (Ilo, 1993; Nitschke M and Pastore MG 2002). This possible misinterpretation occurs because the photometer is calibrated to react to specific chemical changes, which would normally indicate the presence of quaternary ammonium. However, the presence of organic acids and other biochemical compounds can modify the pH or chemical composition of the sample in ways that simulate these changes, resulting in incorrect readings. For example, organic acids can react with test reagents, changing the color of the solution in a way that the photometer interprets as an increase in quaternary ammonia levels.

The complexity of this scenario is intensified by the ability of microorganisms to produce a wide range of secondary metabolites in a dynamic environment such as a WTP. These unforeseen

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interactions between metabolites and chemical test reagents reinforce the importance of using complementary analyzes, such as liquid chromatography and mass spectrometry, for a more precise distinction between compounds. The application of these advanced techniques can provide a clearer view of the chemical transformations occurring at the WTP, ensuring the accuracy of readings and environmental safety. Additional tests were carried out on the Akso Micro 20 Multiparameter Photometer to verify whether the calibration and operation of the equipment were within acceptable error limits, as shown in Table 2.

Table 2: Result of quality analysis, E = +/- 4.8ppm.

Index	P-01	P - 02	P - 03	P - 04
Temperature (°C)	25.6	24.8	26.1	28
DO - Dissolved Oxygen (mg/L)	6	7	5.2	6.2
pH	8.9	9.6	9.2	9.5
NH - Ammonia (ppm)	0	0.01	0	0
NO2 - Nitrite (ppm)	0.07	0.06	0	0.12
NO3 - Nitrate (ppm)	0	0	0	0
PO4 - Phosphate (ppm)	0	0	0.02	0.03
qA-QACs – Quaternary Ammonium Compound (ppm)	7	5.6	8	8.1
S - Sulfide (ppm)	0.03	0.09	0.03	0.03
SO4 - Sulfate (ppm)	0	0.06	7	6
TR1 - Turbidity (NTU)	10	<7.00	21	14

06-01-2024

Index	P-01	P - 02	P - 03	P - 04
Temperature (°C)	24.3	24.6	24.8	24.8
DO - Dissolved Oxygen (mg/L)	6.6	6.3	3.2	3.5
pH	9.6	9.6	9.1	9.1
NH - Ammonia (ppm)	0.06	0	0	0
NO2 - Nitrite (ppm)	0	0.16	0	0
NO3 - Nitrate (ppm)	0	0	0	0
PO4 - Phosphate (ppm)	0	0	0	0.27
qA-QACs – Quaternary Ammonium Compound (ppm)	5.6	5.5	5.7	6.7
S - Sulfide (ppm)	0.03	0.04	0	0.09
SO4 - Sulfate (ppm)	10	17	7	20
TR1 - Turbidity (NTU)	14	14	<7.00	<7.00

06-08-2024
Source: Authors

Index	ppm
Opposite point of ETA	5.5
Well source water filtered on the Milli-Q® Direct Water Purification System	3.6
Water from a well filtered in the Electrolux Purifier	4.2
Water from the air conditioning outlet	0
Precipitation	0

Source: Author

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The results in Table 2 indicate that QACs may come from groundwater contamination. Due to the extensive use of QACs in domestic and industrial products, they reach wastewater treatment plants in substantial quantities. The main sources of QACs released into the environment are effluents and sludge from sewage treatment plants (STPs) (Clara et al., 2007; Martinez-Carballo et al., 2007a; Martinez-Carballo et al., 2007b; Merino et al., 2003a; Li [21]. Other local point sources include hospitals and laundry wastewater (Kümmerer et al., 1997; Kreuzinger et al., 2007). As many solid QACs have melting points in the range of 100-300 °C (Deetlefs, 2006), this rules out the pos-sibility of them being in the atmosphere and contaminating the lake through precipitation, shown in Table 2. The results in Table 3 corroborate that the contamination by QACs in the lake comes from groundwater contamina-tion. The drought has caused a reverse flow of water into the lake, which is infiltrating the soil through cracks. As a re-sult, QACs have reduced their concentration in the lake.

Table 3: Result of quality analysis, E = +/- 4.8ppm (07/06/2024).

Index	P-01	P - 02	P - 03	P - 04
qA-QACs – Quaternary Ammonium Compound (ppm)	0	0	3.8	0

Source: Author

Aquatic Fauna and Improvement in Water Quality

The presence of healthy aquatic fauna and the emergence of large quantities of new fry in the ornamental lake are directly linked to improvements in water quality resulting from bioremediation carried out by a consortium of bioaug-mented Lactobacillus plantarum and Saccharomyces cerevisiae. These microorganisms are known for their effective metabolic processes, which play a crucial role in degrading organic pollutants and reducing toxic compounds. Specifically, Lacto-bacillus plantarum has a significant impact on this process through its fermentation ability, which not only adjusts the pH of the aquatic environment, making it less favorable for the survival of pathogens, but also reduces the solubility of cer-tain toxic pollutants (Moore et al. al., 2018). Furthermore, the enzymes produced by this Lactobacillus are capable of degrading complex organic substances into smaller, less harmful molecules. This enzymatic action contributes to a substantial reduction in the organic load in the water, resulting in an overall improvement in water quality and the aquatic environment [22-38].

At the same time, Saccharomyces cerevisiae plays a vital role by metabolizing nitrogen and other nutrients, which in excess can contribute to eutrophication. This yeast can transform these compounds into cellular biomass or excrete them in less harmful forms, thus helping to control harmful algal blooms and maintain healthy dissolved oxygen levels (Moore et al., 2018). The synergistic interaction between Lactobacillus plantarum and Saccharomyces cerevisiae not only reduces the toxicity of the aquatic environment through the effective degradation of pollutants, but also promotes the creation of a more di-verse and healthier aquatic ecosystem. This biological partnership also reduces water turbidity, which allows greater penetration of sunlight and facilitates photosynthetic processes. The direct consequence of this increase in photosynthe-sis is an increase in dissolved oxygen levels, which is vital for supporting a wider diversity of aquatic species (Moore et al., 2018).

This highlighted bioremediation approach, focused on the specific metabolic processes of these microorganisms, reinforces the importance of targeted biotechnological strategies in the management and recovery of aquatic ecosystems impacted by pollutants. By degrading organic matter, nitrogenous compounds and phosphate, Lactobacillus plantarum and Saccharomyces cerevisiae not only improve water quality, but also contribute significantly to the maintenance of eco-system services, including water purification and supporting complex food webs, essential for health and stability of aquatic ecosystems (Moore et al., 2018).

Conclusions

Based on the results obtained, it is concluded that bioremediation is a promising and effective tool for improving water quality in buffer basins converted into ornamental lakes. The implementation of the Water Treatment Plant (ETA) and the application of bioaugmented microorganisms have proven to be viable and sustainable measures to face the challenges of maintenance and management of these urban environments. However, the detection of quaternary am-monium (qA-CAQ) raises crucial questions about the origin of this compound, indicating the need for further studies to determine whether its presence is due to groundwater contamination, potentially influenced by external factors, or whether it is a byproduct of the metabolic processes of microorganisms used in bioremediation. Only further investigation will clarify this issue and ensure the continued safety and effectiveness of treatment processes. Additionally, this study highlights the immense potential of nature-based solutions to address environmental problems in urban areas, reinforcing the need to prioritize the development and application of green technologies, such as bioremediation. These approaches not only contribute to the recovery of degraded areas, but also promote the sus-tainability and resilience of cities in response to climate change and population growth.

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The experience reported in this work offers valuable contributions to knowledge about bioremediation, providing insights that will be fundamental for future research and practical applications. However, it is imperative to recognize that the effective management of water resources in urban contexts demands an integrated approach, which combines science, technology, community participation, effective public policies and an in-depth understanding of the socioeco-nomic dynamics involved. In summary, while this study celebrates significant advances in improving urban water quality through bioremediation, it also emphasizes the importance of simple, adaptive strategies in water resource management. Continued research and the adoption of innovative practices are essential to ensure a future in which clean and sustainable waters are available for future generations, reaffirming our commitment to the preservation and revitalization of our planet's precious aquatic ecosystems.

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