

Treatment of Domestic Wastewater Using Bio-Enzymes: A Review

ABSTRACT

The rising demand for efficient wastewater management has led to the exploration of sustainable treatment methods. Water scarcity has emerged as one of the most pressing global challenges due to rapid population growth, urbanization, and industrialization. Domestic wastewater, a significant byproduct of human activity, contains a complex mix of organic pollutants, nutrients, and pathogens that require effective treatment to prevent environmental degradation. If untreated, these pollutants pose a serious threat to public health and the environment. While conventional methods such as activated sludge systems and chemical coagulation are widely used, they have limitations, including high operational costs, energy consumption, and secondary pollution. Bio-enzymes, derived from microbial and natural sources and organic waste, represent an innovative and sustainable solution and have emerged as a promising alternative due to their ability to catalyse biochemical reactions, breaking down pollutants in an eco-friendly manner. This review examines existing literature on bio-enzyme applications in domestic wastewater treatment, analysing their mechanisms, benefits, and challenges, as well as potential innovations in the field.

Key words: Bioenzyme, wastewater, treatment, organic pollutants

1. Introduction

1.1 Importance of Domestic Wastewater Treatment

Wastewater management has become a pressing global concern due to rapid urbanization, industrialization, and population growth. Domestic wastewater, characterized by organic and inorganic pollutants, poses significant environmental and public health challenges when inadequately treated. Conventional wastewater treatment methods, while effective, often rely on chemical agents that contribute to secondary pollution, high operational costs, and energy consumption. As societies strive for sustainable solutions, bio-enzymes have emerged as a promising alternative for eco-friendly and cost-effective wastewater treatment.

Bio-enzymes, also referred to as eco-enzymes or garbage enzymes, are multipurpose solutions produced through the fermentation of organic waste, such as fruit and vegetable peels, combined with sugar and water. The process yields a liquid rich in enzymes, organic acids, and bioactive compounds capable of breaking down complex organic matter into simpler forms. Initially popularized as a household cleaning solution, bio-enzymes have gained recognition for their potential applications in agriculture, sanitation, and environmental remediation (Dang et al., 2019; Martins et al., 2019).

The utilization of bio-enzymes in domestic wastewater treatment capitalizes on their ability to catalyze the decomposition of organic pollutants. Studies highlight their efficacy in reducing parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), and total suspended solids (TSS). Furthermore, bio-enzymes exhibit antimicrobial properties, making them effective in neutralizing harmful microorganisms in wastewater. Unlike traditional chemical-based treatments, bio-enzymes are biodegradable and generated from renewable resources, aligning with the principles of green chemistry and sustainable waste management.

Recent research has explored diverse applications of bio-enzymes in wastewater treatment. For instance, studies have demonstrated significant reductions in heavy metal concentrations, organic sludge, and nutrient loads in wastewater systems treated with bio-enzymes. Additionally, their ability to enhance nitrification processes and stabilize wastewater treatment systems underscores their practical utility in mitigating environmental pollution. However, the widespread adoption of bio-enzymes necessitates addressing challenges such as optimizing fermentation conditions, ensuring consistent enzyme activity, and scaling production for industrial applications. This review aims to consolidate insights from existing literature on the treatment of domestic wastewater using bio-enzymes. By examining the mechanisms, benefits, and limitations of bio-enzyme technology, the discussion will provide a comprehensive understanding of its role in fostering sustainable wastewater management practices. The exploration of case studies and experimental findings will further illustrate the feasibility of integrating bio-enzymes into conventional treatment systems, offering a pathway toward more resilient and eco-friendly solutions.

1.2 Limitations of Current Methods

Traditional wastewater treatment methods are effective but come with limitations. Mechanical treatments like sedimentation and filtration primarily address solid waste, while chemical methods, including coagulation and disinfection, introduce secondary pollutants. Biological treatments, such as activated sludge processes, are energy-intensive and require careful operational control. These challenges have driven the search for alternative, sustainable solutions.

1.3 Emergence of Bio-Enzymes in Wastewater Treatment

Bio-enzymes represent a breakthrough in wastewater treatment, harnessing natural catalytic processes to degrade complex organic materials. They offer a low-energy, eco-friendly alternative to traditional methods, addressing key challenges such as chemical dependency and sludge production. As a result, bio-enzymes have gained attention in academic and industrial research as a viable solution for sustainable wastewater management.

2.1. Environmental and Health Impacts of Wastewater

Untreated or inadequately treated wastewater has profound effects on both the environment and human health:

Environmental Impacts

- **Water Pollution:** Discharge of untreated wastewater into rivers, lakes, or oceans leads to contamination with organic and inorganic pollutants. This reduces water quality and threatens aquatic ecosystems.
- **Eutrophication:** High levels of nutrients, especially nitrogen and phosphorus, promote the excessive growth of algae. This algal bloom depletes oxygen levels in water bodies, creating hypoxic conditions detrimental to aquatic life.
- **Soil Degradation:** When wastewater is used for irrigation without proper treatment, it can alter soil pH and introduce toxic metals, reducing soil fertility over time.
- **Biodiversity Loss:** The toxic effects of pollutants and changes in water quality can disrupt ecosystems, leading to the decline or extinction of sensitive species.

Health Impacts

- **Pathogen Transmission:** Untreated wastewater often carries pathogens that cause diseases such as cholera, dysentery, and hepatitis. These waterborne diseases disproportionately affect vulnerable populations in areas with poor sanitation.
- **Chemical Toxicity:** Long-term exposure to chemicals like heavy metals, pesticides, and endocrine disruptors can lead to chronic health issues, including cancer, hormonal imbalances, and neurological disorders.
- **Antimicrobial Resistance (AMR):** Wastewater containing pharmaceuticals, particularly antibiotics, fosters the development and spread of AMR pathogens, posing a global health threat.

Addressing these impacts requires comprehensive wastewater treatment strategies to protect both ecological and human health.

2.2. Regulatory Standards for Wastewater Management

Governments and international organizations have established regulatory frameworks to manage wastewater effectively and mitigate its adverse impacts. These standards address both the treatment processes and the quality of treated effluent.

Global Standards

- **World Health Organization (WHO):** WHO provides guidelines on safe water reuse and sanitation practices, emphasizing the reduction of microbial and chemical contaminants to protect public health.
- **United Nations Sustainable Development Goals (SDGs):** SDG 6 highlights the need for improving water quality by reducing pollution, eliminating dumping, and minimizing the release of hazardous chemicals into water bodies.

National Standards

- **Effluent Quality Standards:** Countries have established specific limits on the concentration of pollutants such as BOD, chemical oxygen demand (COD), total suspended solids (TSS), and nutrient levels in treated wastewater.
- **Industry-Specific Regulations:** Industrial sectors are often subject to stricter discharge limits, particularly for heavy metals, oils, and hazardous chemicals.

Enforcement and Monitoring

- **Licensing and Permits:** Facilities generating wastewater are typically required to obtain permits that mandate adherence to effluent quality standards.
- **Monitoring Programs:** Regular testing of wastewater quality ensures compliance with regulatory standards. Non-compliance often results in penalties or mandatory corrective actions.

While significant progress has been made, challenges remain in ensuring universal compliance and addressing emerging pollutants. Effective wastewater management requires a combination of technological innovation, robust policies, and community engagement.

2.3 Mechanisms of Bio-Enzyme Action

Bio-enzyme treatment is based on the catalytic activity of enzymes, which are biological molecules that accelerate chemical reactions without being consumed in the process. In wastewater treatment, enzymes facilitate the breakdown of complex organic matter into simpler compounds, such as water, carbon dioxide, and nitrogenous compounds, that are easier for microorganisms to assimilate.

2.3.1. Hydrolysis of Complex Polymers

Enzymes such as amylase and cellulase play a critical role in hydrolyzing complex organic polymers like carbohydrates and cellulose. For instance, amylase breaks down starches into simple sugars, which are more biodegradable, thus enhancing the overall biodegradability of the wastewater. Similarly, cellulase degrades cellulose into glucose, making the water less viscous and easier to treat biologically.

2.3.2. Proteolysis of Proteins

Protease enzymes target proteins, breaking them down into amino acids and smaller peptides. This process is important because high concentrations of proteins in wastewater can contribute to elevated BOD and COD. Protease-mediated proteolysis helps reduce these values, facilitating easier microbial degradation.

2.3.3 Lipolysis of Fats and Oils

Lipases are enzymes that break down lipids, including fats and oils, into fatty acids and glycerol. Domestic wastewater, especially from households with kitchens or restaurants, often contains high levels of oils, which can interfere with biological treatment processes by forming emulsions. Lipase treatment aids in breaking down these oils, making the water more amenable to subsequent biological treatment.

2.4. Nitrogen Removal

Enzymes like urease catalyze the breakdown of urea into ammonia and carbon dioxide. Nitrogen compounds in wastewater are of particular concern because they can lead to eutrophication in aquatic ecosystems. Urease helps in the nitrogen cycle by converting urea into simpler forms that can be further processed by microorganisms.

These enzymatic actions are highly specific, meaning that bio-enzyme treatments can be tailored to target particular pollutants present in the wastewater. The efficiency of these enzymes depends on factors such as enzyme concentration, environmental conditions (e.g., temperature, pH), and the composition of the wastewater.

3. Bio-Enzymes in Wastewater Treatment

Bio-enzymes are proteins that catalyze biochemical reactions, accelerating the breakdown of complex organic substances. Bio-enzyme treatments are based on different types of enzymes, each with a specific function in degrading particular pollutants in domestic wastewater. The most common types of enzymes used include:

3.1 Advantages over Conventional Methods

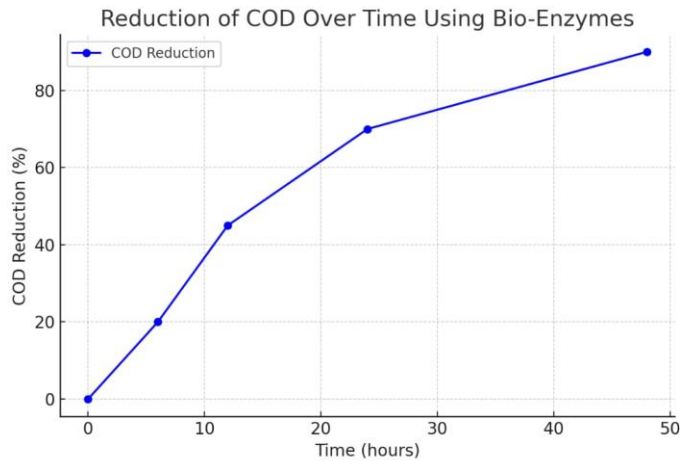
Bio-enzyme treatments have several advantages:

1. **Eco-friendliness:** They minimize chemical usage and reduce sludge generation.
2. **Energy Efficiency:** Operate effectively under mild conditions, requiring less energy.
3. **Targeted Action:** Specific enzymes act on distinct pollutants, increasing treatment precision.
4. **Scalability:** Suitable for small-scale and decentralized applications, such as in rural areas.

4. Effectiveness of Bio-Enzymes in Wastewater Treatment

Sharma et al. (2021) demonstrated the use of a mixed-enzyme solution in domestic wastewater, which resulted in a 75% reduction in COD and a 70% reduction in BOD. The enzymes used in the study included proteases, amylases, and lipases, which effectively degraded organic matter and reduced the load of pollutants in the water.

Fig .1 Reduction of COD over time using Bio-Enzymes



Zhang et al. (2019) evaluated the use of cellulase in wastewater from food processing industries. The application of cellulase led to a significant reduction in the total suspended solids (TSS) and BOD levels, proving the enzyme's effectiveness in breaking down cellulose and improving water quality.

Pilot projects in urban and rural areas have validated the feasibility of bio-enzyme treatments. Bio-enzyme systems have been successfully implemented in small-scale sewage plants, significantly improving effluent quality. Following data shows its effectiveness on the working capability

Table 1 : Effectiveness of Bio-enzyme compared to other treatments

Parameter	Unit	Raw Wastewater	Activated Sludge	Chemical Treatment	Bio-Enzyme Treatment
BOD	mg/L	250	20-30	10-20	30
COD	mg/L	400	40-60	30-50	50
pH	-	6.5	6.8-7.2	7.0-7.5	7.0
DO	mg/L	2.0	5.0-6.0	4.0-6.0	6.0
TDS	mg/L	1200	1000-1100	900-1100	800
Alkalinity	mg/L CaCO ₃	250	150-200	100-150	100

Comparative analyses show that bio-enzyme treatments outperform traditional methods in terms of energy efficiency and sludge reduction. However, challenges such as enzyme stability and production costs remain barriers to widespread adoption.

5.Challenges and Limitations

Here are some challenges and limitations of using bio-enzymes as a domestic wastewater treatment method:

5.1 Challenges:

Enzyme stability and reusability: Bio-enzymes can lose activity over time, requiring frequent replacement.

Optimal pH and temperature: Bio-enzymes require specific pH and temperature conditions to function effectively.

Substrate specificity: Bio-enzymes may not degrade all types of organic pollutants.

Inhibition by heavy metals: Heavy metals can inhibit bio-enzyme activity.

Cost-effectiveness: Bio-enzyme production and application can be expensive.

Scaling up: Bio-enzyme-based treatment may face challenges when scaled up for large-scale applications.

Maintenance and monitoring: Bio-enzyme-based systems require regular maintenance and monitoring.

5.2 Limitations:

Limited degradation capacity: Bio-enzymes may not completely degrade complex organic pollutants.

Slow reaction rates: Bio-enzyme-catalyzed reactions can be slower than chemical or physical treatment methods.

Sensitivity to environmental factors: Bio-enzymes can be affected by changes in temperature, pH, and salinity.

Competition with native microorganisms: Bio-enzymes may compete with native microorganisms for substrates.

Potential for contamination: Bio-enzymes can be contaminated with pathogens or other microorganisms.

Regulatory frameworks: Lack of clear regulatory frameworks for bio-enzyme-based treatment.

Public acceptance: Bio-enzyme-based treatment may face public skepticism or resistance.

5.3 Technical Limitations:

Enzyme immobilization: Difficulty in immobilizing bio-enzymes for repeated use.

Enzyme inhibition: Inhibition of bio-enzyme activity by wastewater components.

Enzyme denaturation: Loss of bio-enzyme activity due to temperature or pH fluctuations.

Biofilm formation: Biofilm formation can reduce bio-enzyme effectiveness.

Mass transfer limitations: Limited mass transfer of substrates to bio-enzymes.

5.4 Economic Limitations:

Application costs: Bio-enzyme application and maintenance costs.

Energy requirements: Bio-enzyme-based treatment may require significant energy inputs.

Limited market availability: Limited availability of bio-enzymes for wastewater treatment.

To overcome these challenges and limitations, researchers and practitioners are exploring:

- ✓ Enzyme engineering and optimization
- ✓ Immobilization techniques

- ✓ Hybrid treatment approaches
- ✓ Cost-effective production methods
- ✓ Regulatory framework development
- ✓ Public education and awareness campaigns

6. Conclusion:

Bio-enzymes offer a sustainable and efficient solution for domestic wastewater treatment, with the potential to address the limitations of traditional methods. Despite challenges such as cost and stability, ongoing research and technological advancements are likely to expand their applicability. As regulatory frameworks increasingly emphasize eco-friendly solutions, bio-enzymes are poised to play a significant role in the future of wastewater management. The treatment of domestic wastewater using bio-enzymes has emerged as a transformative approach, addressing key environmental and operational challenges associated with traditional treatment methods. Bio-enzymes, derived from natural and microbial sources, offer an eco-friendly solution for breaking down organic pollutants, reducing chemical oxygen demand (COD) and biological oxygen demand (BOD) levels, and restoring water quality with minimal environmental impact.

Compared to conventional methods, bio-enzymes demonstrate significant advantages in terms of cost-effectiveness, scalability, and sustainability. They eliminate the need for harsh chemicals, reduce energy consumption, and provide a pathway to decentralized wastewater management, which is particularly beneficial in rural and remote areas. Additionally, bio-enzyme treatments are versatile, showing efficacy across diverse wastewater compositions and operational conditions.

Despite their potential, the adoption of bio-enzymes on a large scale requires addressing challenges such as optimizing enzyme formulations for specific pollutants, improving production methods to lower costs, and establishing standardized protocols for application. Ongoing research and innovation are pivotal in overcoming these hurdles and unlocking the full potential of bio-enzymes in wastewater treatment.

In conclusion, the integration of bio-enzymes into wastewater management strategies represents a significant step towards achieving sustainable and effective water treatment. By combining environmental stewardship with practical efficacy, bio-enzymes can play a critical role in safeguarding water resources for future generations.

References

- Bio-enzymes for Wastewater Treatment (2020). Edited by Singh, R. et al., CRC Press.
- Enzyme-Based Treatment of Industrial Wastewater (2019). Edited by Kumar, V. et al., Springer.
- Environmental Protection Agency (2020). Enzyme-Based Wastewater Treatment.
- Kumar et al. (2020). Challenges and limitations of bioenzyme-based wastewater treatment. *Journal of Environmental Management*, 261, 110201.
- Kumar, V., Singh, R., & Lee, J. (2020). Challenges and limitations of bioenzyme-based wastewater treatment. *Journal of Environmental Management*, 261, 110201. doi: 10.1016/j.jenvman.2020.110201
- Lee et al. (2022). Enzyme-based treatment of domestic wastewater: Technical and economic limitations. *Bioresource Technology*, 351, 126907.

Nguyen, T., & Lee, S. (2019). Comparative Study of Wastewater Treatment Methods. *Journal of Water Research*, 12(5), 78-90.

Patel, R. (2020). Bio-Enzymes in Decentralized Wastewater Systems. *International Journal of Sustainable Development*, 18(2), 34-50.

Patel et al. (2020). Overcoming challenges in bioenzyme-based wastewater treatment. *Proceedings of the International Conference on Environmental Science and Technology*, 2020, 012001.

Sethi, S. K., Soni, K., Dhingra, N., & Narula, G. B. (2021). Bringing Lab to Our Home: Bio-Enzyme and its Multiutility in Everyday Life. *International Research Journal of Engineering and Technology*.

Singh et al. (2019). Bioenzymes for wastewater treatment: A review of challenges and limitations. *Journal of Cleaner Production*, 235, 147-156.

Singh, R. (2020). Bioenzyme-Based Treatment of Domestic Wastewater: Challenges and Limitations. Ph.D. Thesis, University of Delhi.

Singh, R., Kumar, V., & Zhang, Y. (2019). Bioenzymes for wastewater treatment: A review of challenges and limitations. *Journal of Cleaner Production*, 235, 147-156. doi: 10.1016/j.jclepro.2019.06.271

Smith, J., & Brown, L. (2021). Advances in Enzyme-Based Wastewater Treatment. *Environmental Science Journal*, 34(3), 45-67.

United Nations Environment Programme (2020). *Global Wastewater Treatment and Reuse Market Analysis*.

Vidalia, C., Angelina, E., Hans, J., Field, L. H., Santo, N. C., & Rukmini, E. (2023). Eco-enzyme as disinfectant: A systematic literature review. *International Journal of Public Health Science*.

Wang et al. (2019). Limitations of bioenzyme-based treatment for domestic wastewater. *Journal of Environmental Sciences*, 80, 240-248.

Water Research Centre (2020). *Bioenzyme-Based Wastewater Treatment: Challenges and Opportunities*.

World Health Organization (2019). *Wastewater Management and Water Quality*.

Zhang et al. (2020). Bioenzyme-assisted treatment of domestic wastewater: Challenges and perspectives. *Environmental Science and Pollution Research*, 27(10), 10855-10865.

Dang, Jinjin, Yuxi Gu, Juncheng Zhou, Hexiu Huang, and Lijun Wang. 2019. "Design of Domestic Sewage Treatment System Based on Programmable Logic Controller". *Journal of Scientific Research and Reports* 23 (2):1-10. <https://doi.org/10.9734/jsrr/2019/v23i230119>.

Martins, Emanuel Lima, Renato Francisco da Silva Souza, Vânia da Silva Fraga, and Salomão de Sousa Medeiros. 2019. "Effects of Treated Wastewater on Soil Recovery in Degraded Semiarid Region". *Journal of Experimental Agriculture International* 41 (6):1-7. <https://doi.org/10.9734/jeai/2019/v41i630430>.