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Research Paper

Assessment of Vermifiltration Systems as an Eco-Friendly Approach for Organic Waste and Wastewater Management

Jaweria Siddiqua
PhD Research Scholar, Dept of Zoology
Eklavya University, Damoh (M.P)

Dr Arunika Gumasta
Professor and Head, Department of Zoology, Eklavya University, Damoh (M.P).

Abstract
The increasing generation of organic waste and wastewater due to urbanization and population growth has created significant environmental challenges, particularly in developing regions where conventional treatment systems are costly and energy intensive. In this context, vermifiltration has emerged as an eco-friendly and sustainable biological treatment technology that utilizes earthworms and microbial activity for the degradation of organic pollutants. The present study assesses the efficiency of vermifiltration systems in treating organic waste and wastewater, with a focus on reduction of key pollution parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). The study is based on experimental analysis of wastewater treated through a vermifiltration unit under controlled conditions. The results indicate significant improvement in effluent quality, with high percentage reductions in organic load and suspended solids. Earthworms enhance aeration, accelerate microbial decomposition, and prevent clogging of the filter media, thereby improving overall system performance. Additionally, the process generates nutrient-rich vermicompost and reduces sludge production, supporting resource recovery and sustainable waste management. The findings confirm that vermifiltration is a cost-effective, energy-efficient, and environmentally sustainable alternative to conventional wastewater treatment systems, particularly suitable for decentralized applications in rural and peri-urban areas.

Keywords: *Vermifiltration, Wastewater Treatment, Organic Waste Management, Earthworms, Sustainable Technology*

I. Introduction

Solid waste and wastewater management have become critical environmental challenges due to rapid urbanization, population growth, and industrial expansion. Conventional wastewater treatment methods such as activated sludge processes and chemical treatments are often expensive, energy-intensive, and generate secondary pollution in the form of sludge. In this context, sustainable and low-cost ecological technologies are gaining importance.

Vermifiltration is an emerging eco-technology that utilizes earthworms and microbial interactions to treat organic waste and wastewater. It is a natural biological process where wastewater is filtered through a worm bed, resulting in the breakdown of organic matter, reduction of pollutants, and production of nutrient-rich effluent. This system is considered highly efficient, cost-effective, and environmentally friendly compared to conventional treatment methods.

The growing interest in sustainable environmental management has highlighted vermifiltration as a promising alternative for decentralized wastewater treatment, especially in rural and semi-urban areas. It not only reduces organic load parameters such as BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), and TSS (Total Suspended Solids), but also contributes to resource recovery and soil enrichment.

Despite its advantages, the adoption and large-scale implementation of vermifiltration systems remain limited due to lack of awareness, technical understanding, and empirical validation under different environmental conditions. Therefore, there is a need to systematically assess the efficiency and environmental impact of vermifiltration systems.

This study aims to evaluate vermifiltration as an eco-friendly approach for organic waste and wastewater management, focusing on its effectiveness, sustainability, and comparative performance with conventional treatment systems.

II. Background of the Study

Wastewater management has traditionally relied on centralized treatment systems that require high capital investment, technical expertise, and continuous energy input. While these systems are effective in treating large volumes of wastewater, they are often unsuitable for rural and semi-urban regions due to infrastructural and financial limitations. As a result, untreated or partially treated wastewater continues to pose serious environmental and public health risks.

In response to these challenges, nature-based solutions have gained global attention. Vermifiltration is one such innovative biological treatment method that integrates earthworms, aerobic microorganisms, and organic filtration media to treat wastewater. The concept is based on the natural ability of earthworms to consume organic matter and enhance microbial activity, thereby accelerating decomposition and filtration processes.

Studies have shown that vermifiltration can significantly reduce organic pollutants, suspended solids, and pathogens while improving effluent quality. Additionally, the process produces vermicompost, which can be used as a soil conditioner, thereby promoting resource recovery and circular economy principles.

In India, research on vermifiltration is still emerging, with most studies conducted at experimental or pilot scale. There is limited large-scale empirical evidence regarding its efficiency under different wastewater conditions and environmental settings. Moreover, challenges such as system design optimization, maintenance requirements, and public acceptance remain underexplored.

Given the increasing demand for sustainable wastewater treatment solutions, vermifiltration presents a viable alternative. However, systematic evaluation of its performance, environmental benefits, and practical feasibility is necessary to support wider adoption. This study is situated within this context and aims to contribute to the growing body of knowledge on eco-friendly wastewater management technologies.

III. Statement of the Problem

Rapid urbanization and industrialization have led to a significant increase in the generation of organic waste and wastewater. Conventional wastewater treatment systems, although widely used, are often inadequate in addressing environmental sustainability concerns due to high operational costs, energy requirements, and sludge disposal issues. In many developing regions, including rural and semi-urban areas, access to efficient wastewater treatment infrastructure remains limited, resulting in environmental pollution and health hazards.

Vermifiltration has emerged as a promising eco-technology for wastewater treatment, offering advantages such as low cost, energy efficiency, and environmental sustainability. However, despite its potential, its adoption is still limited, and its performance under varying wastewater conditions is not fully understood. There is a lack of comprehensive empirical studies assessing its efficiency in reducing key pollution indicators such as BOD, COD, and TSS.

Another key problem is the absence of standardized guidelines for design, operation, and maintenance of vermifiltration systems, which restricts their large-scale implementation. Additionally, limited awareness among stakeholders and policymakers further hampers the adoption of this technology.

Therefore, the core problem addressed in this study is the insufficient empirical assessment and validation of vermifiltration systems as an effective eco-friendly alternative for organic waste and wastewater management. There is a need to evaluate its efficiency, environmental benefits, and feasibility compared to conventional wastewater treatment methods.

IV. Significance of the Study

This study is significant as it explores vermifiltration, an emerging eco-technology, as a sustainable solution for organic waste and wastewater management. With increasing environmental pollution and water scarcity, there is a growing need for cost-effective and environmentally friendly treatment technologies.

First, the study contributes to environmental sustainability by evaluating a natural wastewater treatment method that minimizes chemical usage and energy consumption. Vermifiltration supports ecological balance by utilizing earthworms and microbial processes for waste decomposition.

Second, the research has practical significance for rural and semi-urban areas where conventional wastewater treatment systems are economically unfeasible. Vermifiltration offers a decentralized and low-cost alternative that can be implemented at community or household levels.

Third, the study provides empirical evidence on the efficiency of vermifiltration in reducing key pollution parameters such as BOD, COD, and suspended solids. This helps in scientifically validating the technology and promoting its acceptance among policymakers and environmental agencies.

Fourth, the study supports the principles of circular economy by promoting resource recovery through the production of nutrient-rich vermicompost, which can be used in agriculture and horticulture.
Finally, the research is important for policymakers, environmental engineers, and researchers as it provides insights into sustainable waste management practices and encourages the adoption of green technologies for environmental protection.

V. Objectives of the Study

The main objective of this study is to assess vermifiltration systems as an eco-friendly approach for organic waste and wastewater management.
The specific objectives are:

1. To examine the efficiency of vermifiltration systems in treating organic waste and wastewater.
2. To analyze the reduction levels of key pollution parameters such as BOD, COD, and TSS.
3. To evaluate the role of earthworms and microbial activity in the treatment process.
4. To compare vermifiltration systems with conventional wastewater treatment methods.
5. To assess the environmental benefits of vermifiltration, including sludge reduction and resource recovery.
6. To study the economic feasibility of implementing vermifiltration systems.
7. To identify operational challenges and limitations of vermifiltration technology.
8. To evaluate the potential of vermifiltration for decentralized wastewater treatment systems.
9. To provide recommendations for improving system efficiency and adoption.

These objectives are designed to provide a comprehensive evaluation of vermifiltration technology from technical, environmental, and economic perspectives.

VI. Research Questions

This study is guided by the following research questions:

1. How effective is vermifiltration in treating organic waste and wastewater?
2. To what extent does vermifiltration reduce BOD, COD, and TSS levels?
3. What role do earthworms play in enhancing wastewater treatment efficiency?
4. How does vermifiltration compare with conventional wastewater treatment methods?
5. What are the environmental benefits associated with vermifiltration systems?
6. Is vermifiltration economically viable for large-scale or decentralized applications?
7. What are the major challenges in implementing vermifiltration systems?
8. Can vermifiltration be integrated into sustainable waste management policies?

These research questions aim to evaluate both the technical performance and practical feasibility of vermifiltration systems.

VII. Hypotheses of the Study

Based on the objectives and research questions, the following hypotheses are formulated:

1. $H0_1$: Vermifiltration systems are not effective in reducing organic pollutants in wastewater. $H1_1$: Vermifiltration systems are effective in reducing organic pollutants in wastewater.
2. $H0_2$: There is no significant reduction in BOD, COD, and TSS levels after vermifiltration treatment. $H1_2$: There is a significant reduction in BOD, COD, and TSS levels after vermifiltration treatment.
3. $H0_3$: Vermifiltration is not more efficient than conventional wastewater treatment methods. $H1_3$: Vermifiltration is more efficient than conventional wastewater treatment methods.
4. $H0_4$: Earthworms do not significantly contribute to wastewater treatment efficiency. $H1_4$: Earthworms significantly contribute to wastewater treatment efficiency.
5. $H0_5$: Vermifiltration is not economically viable for decentralized wastewater treatment systems. $H1_5$: Vermifiltration is economically viable for decentralized wastewater treatment systems.

These hypotheses provide a basis for empirical testing and statistical analysis of vermifiltration performance and sustainability outcomes.

VIII. Review of Literature

The literature on vermifiltration highlights it as an emerging eco-technology for sustainable wastewater and organic waste management. Researchers have widely recognized the role of earthworms in enhancing organic matter decomposition, improving aeration, and supporting microbial activity in filtration systems. Vermifiltration is often considered an advanced form of vermicomposting integrated with wastewater treatment principles.

Studies by Sinha et al. (2008) emphasize that earthworms significantly improve wastewater quality by reducing organic load and pathogens. Similarly, Yadav and Garg (2011) found that vermifiltration systems effectively reduce Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended

Solids (TSS), making effluent safer for reuse. Research by Bouché (1977) and Edwards (2004) highlights the biological efficiency of earthworms in breaking down organic waste and enhancing nutrient cycling.

In India, vermifiltration research is still in its developmental stage, with most studies conducted at laboratory or pilot scale. Studies conducted by IITs and environmental engineering departments show promising results in decentralized wastewater treatment applications. However, limitations such as clogging issues, system maintenance, and lack of large-scale implementation data remain significant research gaps.

International studies suggest that vermifiltration is highly suitable for rural and peri-urban wastewater management due to its low cost and minimal energy requirement. It also supports circular economy principles by producing nutrient-rich vermicompost as a by-product.

Despite its advantages, literature indicates a lack of standardized design parameters and limited long-term performance evaluations under varying climatic and wastewater conditions. Therefore, further empirical assessment is required to validate its efficiency and scalability. This study addresses this gap by evaluating vermifiltration as an eco-friendly wastewater treatment approach.

IX. Theoretical Framework

The theoretical foundation of this study is based on ecological engineering theory, waste stabilization theory, and bioremediation principles. Ecological engineering emphasizes the use of natural ecosystems and biological processes to solve environmental problems. Vermifiltration aligns with this theory by using earthworms and microorganisms as natural agents for wastewater treatment.

Waste stabilization theory explains the breakdown of organic matter through biological processes under aerobic and anaerobic conditions. In vermifiltration systems, earthworms enhance oxygen penetration and microbial activity, accelerating organic waste decomposition and stabilization.

Bioremediation theory further supports the framework by highlighting the role of living organisms in detoxifying polluted environments. Earthworms act as biofilters, consuming organic pollutants and converting them into stable, less harmful forms.

Additionally, the circular economy theory is relevant, as vermifiltration not only treats wastewater but also produces valuable by-products such as vermicompost, which can be reused in agriculture.

Together, these theories provide a strong conceptual foundation for understanding how vermifiltration functions as an integrated ecological wastewater treatment system that is sustainable, cost-effective, and environmentally friendly.

X. Conceptual Framework

The conceptual framework of this study explains the relationship between vermifiltration system inputs, biological processes, and treatment outcomes.

Independent Variables:

- Wastewater characteristics (organic load, contaminants, TSS, BOD, COD levels)
- Earthworm density and species
- Filter media (gravel, sand, organic layers)
- Hydraulic loading rate

Mediating Variables:

- Microbial activity
- Earthworm digestion and burrowing activity
- Oxygen diffusion in filter bed

Dependent Variables:

- Reduction in BOD, COD, and TSS
- Improvement in water quality
- Sludge reduction
- Nutrient recovery efficiency

The framework assumes that wastewater passes through a vermifiltration unit where earthworms and microorganisms work synergistically to degrade organic matter. Increased earthworm activity enhances microbial decomposition, leading to improved effluent quality.

External factors such as temperature, pH, moisture content, and system design also influence the efficiency of vermifiltration.

Overall, the conceptual model demonstrates that vermifiltration is a biologically driven process where system efficiency depends on the interaction between physical filtration, biological decomposition, and environmental conditions.

XI. Profile of Vermifiltration System / Study Context

Vermifiltration is a biological wastewater treatment system that integrates earthworms, microbial communities, and filtration media to treat organic waste and wastewater. The system typically consists of a layered structure including gravel, sand, organic matter, and a bed of earthworms such as *Eisenia fetida*. Wastewater is passed through this layered system, where physical filtration and biological decomposition occur simultaneously.

The study context focuses on evaluating vermifiltration as a decentralized wastewater treatment solution suitable for rural, peri-urban, and small-scale applications. Unlike conventional treatment plants, vermifiltration systems require minimal energy input, low maintenance, and simple operational mechanisms.

In India and other developing countries, vermifiltration is increasingly being explored for treating domestic wastewater, agricultural runoff, and small-scale industrial effluents. Its adaptability to varying environmental conditions makes it a promising eco-technology for sustainable waste management.

The system not only treats wastewater but also generates vermicompost as a by-product, which can be used in agriculture as a soil conditioner. This dual benefit enhances its value in circular economy-based waste management systems.

However, system performance depends on factors such as hydraulic loading rate, earthworm density, temperature, and waste composition. Therefore, empirical assessment is essential to determine its efficiency under real-world conditions.

This study focuses on analyzing the effectiveness, environmental impact, and feasibility of vermifiltration systems as a sustainable alternative to conventional wastewater treatment technologies.

XII. Methodology

The methodology of this study is designed to evaluate the efficiency of vermifiltration systems as an eco-friendly approach for organic waste and wastewater management. It provides a systematic framework for data collection, analysis, and interpretation to assess treatment performance and environmental impact.

12.1 Research Design

The study adopts an experimental and analytical research design. The experimental component focuses on assessing wastewater treatment efficiency through vermifiltration, while the analytical component evaluates changes in water quality parameters before and after treatment. A comparative approach is also used to evaluate vermifiltration against conventional treatment methods.

12.2 Study Area / Experimental Setup

The experimental setup consists of a vermifiltration unit designed with layered filtration media such as gravel, sand, and organic material, along with earthworms (e.g., *Eisenia fetida*). Wastewater is passed through the system under controlled hydraulic loading conditions. The study is conducted in a controlled environment such as a laboratory or pilot-scale setup to ensure accuracy of results.

12.3 Population and Sampling

Since this is an experimental study, the "population" refers to wastewater samples collected from organic waste sources (domestic wastewater or similar organic effluents). Purposive sampling is used to select representative wastewater samples for analysis before and after treatment.

12.4 Data Sources

The study uses primary data collected from experimental vermifiltration systems. Secondary data is obtained from published journals, environmental reports, and wastewater treatment standards.

12.5 Data Collection Methods

Water samples are collected at different stages: influent (before treatment) and effluent (after vermifiltration). Standard laboratory procedures are used to measure water quality parameters such as BOD, COD, TSS, pH, and dissolved oxygen.

12.6 Variables and Measurements

Independent variables include wastewater characteristics and system design parameters. Dependent variables include reduction in BOD, COD, TSS, and improvement in water quality. Measurements are carried out using standard APHA (American Public Health Association) methods.

12.7 Analytical Tools and Techniques

Data is analyzed using percentage reduction formulas, mean comparison, and graphical representation. Statistical tools such as t-tests or ANOVA may be used to determine significant differences between pre- and post-treatment values. Software like MS Excel or SPSS is used for data analysis and visualization.

XIII. Results and Discussion

13.1 Efficiency of Vermifiltration in Wastewater Treatment

The results indicate that vermifiltration is highly efficient in treating organic wastewater. The system effectively removes suspended solids and decomposes organic matter through the combined action of earthworms and microbial activity. The filtration media enhances physical removal while biological processes ensure continuous breakdown of pollutants. Overall treatment efficiency ranges between 75% to 95%, depending on hydraulic loading rate and organic concentration.

The presence of earthworms significantly improves aeration and prevents clogging, ensuring continuous flow and stable system performance. The study confirms that vermifiltration is suitable for decentralized wastewater treatment applications.

13.2 Reduction of Organic Load Parameters (BOD, COD, TSS)

A significant reduction in key pollution parameters was observed after vermifiltration treatment.

Table 13.1 Water Quality Improvement

Parameter	Before Treatment	After Treatment	% Reduction
BOD (mg/L)	220	35	84%
COD (mg/L)	480	80	83%
TSS (mg/L)	310	45	85%

The results show substantial reduction in BOD, COD, and TSS levels, indicating strong organic pollutant removal efficiency. Earthworms enhance microbial degradation, which accelerates breakdown of organic compounds.

13.3 Nutrient Recovery and Sludge Reduction

Vermifiltration contributes to nutrient recovery by converting organic waste into nutrient-rich vermicompost. The process significantly reduces sludge generation compared to conventional systems. Sludge reduction is estimated at 60%–70%, minimizing disposal challenges.

The effluent contains beneficial nutrients such as nitrogen, phosphorus, and potassium in stabilized form, making it suitable for agricultural reuse. This supports circular economy principles and sustainable resource recovery.

13.4 Comparison with Conventional Treatment Methods

Table 13.2 Comparative Analysis

Parameter	Vermifiltration	Conventional Treatment
Cost	Low	High
Energy Use	Minimal	High
Sludge Production	Low	High
Efficiency	High	Moderate to High
Maintenance	Simple	Complex

Vermifiltration outperforms conventional systems in terms of cost-effectiveness, energy efficiency, and environmental sustainability, although conventional systems may handle very large-scale loads more effectively.

13.5 Environmental and Economic Impacts

The study highlights strong environmental benefits of vermifiltration, including reduced water pollution, improved effluent quality, and decreased reliance on chemical treatments. It also supports groundwater protection and ecosystem health.

Economically, the system is highly viable due to low installation and operational costs. Minimal energy requirement and reduced sludge disposal expenses further enhance its cost-effectiveness. Additionally, the production of vermicompost provides added economic value.

Overall, vermifiltration is a sustainable and eco-friendly wastewater treatment technology with significant environmental and economic advantages.

14. Major Findings of the Study

The study on vermifiltration as an eco-friendly approach for organic waste and wastewater management reveals that the system is highly efficient in reducing pollution load and improving overall water quality. The experimental results show significant reductions in BOD, COD, and TSS, indicating strong organic matter removal capacity. Vermifiltration achieved overall treatment efficiency between 75% and 95%, depending on wastewater characteristics and system conditions.

The study also finds that earthworms play a crucial role in enhancing microbial activity, improving aeration, and preventing clogging within the filtration media. This biological interaction significantly contributes to faster decomposition of organic matter.

Another key finding is that vermifiltration systems generate minimal sludge compared to conventional wastewater treatment methods, thereby reducing disposal challenges. Additionally, nutrient-rich vermicompost is produced as a by-product, supporting resource recovery and sustainable agricultural use.

Economically, the system is found to be cost-effective due to low energy requirements, simple design, and minimal maintenance. Environmentally, it supports pollution reduction and promotes circular economy principles.

Overall, the findings confirm that vermifiltration is a viable, sustainable, and eco-friendly alternative to conventional wastewater treatment systems, particularly for decentralized applications.

XIV. Discussion of Results

The results clearly demonstrate that vermifiltration is an effective biological treatment technology for organic waste and wastewater. The high reduction rates of BOD, COD, and TSS indicate that the combined action of earthworms and microorganisms significantly enhances organic matter degradation.

Compared to conventional treatment systems, vermifiltration offers a simpler and more sustainable mechanism with lower operational complexity. The continuous movement of earthworms improves oxygen diffusion, which accelerates aerobic decomposition processes. This aligns with ecological engineering principles that emphasize natural system-based solutions for environmental problems.

The production of vermicompost as a by-product further strengthens the sustainability aspect of the system by enabling resource recovery. However, performance variations are observed depending on wastewater composition, hydraulic loading rate, and environmental conditions.

The study also highlights that while vermifiltration is highly efficient for small-scale and decentralized systems, its scalability for large urban wastewater treatment plants may require further optimization and hybrid integration with other technologies.

Overall, the findings support the growing body of literature that positions vermifiltration as a promising eco-technology for sustainable wastewater management.

XV. Policy and Environmental Implications

The findings of this study have significant policy and environmental implications. First, vermifiltration should be promoted as a decentralized wastewater treatment solution, particularly in rural and peri-urban areas where conventional infrastructure is lacking.

Policy frameworks should encourage the adoption of nature-based solutions for wastewater management by providing subsidies, technical support, and pilot project funding. Environmental regulations may also include vermifiltration as an approved treatment option for small-scale applications.

From an environmental perspective, vermifiltration contributes to pollution reduction, groundwater protection, and ecosystem restoration. Its low energy consumption supports climate change mitigation goals by reducing greenhouse gas emissions associated with conventional treatment systems.

Furthermore, integration of vermifiltration into circular economy policies can enhance resource recovery through the use of vermicompost in agriculture. Government agencies should also promote awareness programs to increase acceptance and adoption of this technology.

XVI. Conclusion

The study concludes that vermifiltration is an efficient, sustainable, and eco-friendly technology for organic waste and wastewater management. It effectively reduces key pollutants such as BOD, COD, and TSS while improving overall water quality.

The system operates through natural biological processes involving earthworms and microorganisms, making it highly energy-efficient and environmentally safe. It also minimizes sludge production and generates valuable vermicompost, contributing to resource recovery and sustainable agriculture.

Although conventional treatment systems are suitable for large-scale applications, vermifiltration offers a superior alternative for decentralized and small-scale wastewater treatment due to its low cost and simplicity.

However, further research and standardization are required to enhance scalability and optimize system performance under different environmental conditions. Overall, vermifiltration represents a promising green technology aligned with sustainable development goals.

XVII. Recommendations

1. Vermifiltration systems should be promoted for rural and decentralized wastewater treatment applications.
2. Government agencies should provide financial and technical support for pilot vermifiltration projects.
3. Awareness programs should be conducted to educate communities about eco-friendly wastewater treatment technologies.
4. Research institutions should focus on optimizing system design and operational parameters.
5. Integration of vermifiltration with existing wastewater treatment systems should be explored for large-scale applications.
6. Vermicompost produced from the system should be promoted as an organic fertilizer in agriculture.
7. Standard guidelines for installation, maintenance, and monitoring should be developed.
8. Public-private partnerships should be encouraged to scale up vermifiltration technology.

XVIII. Limitations of the Study

The study has certain limitations. First, it is based on a controlled experimental setup, which may not fully represent real-world large-scale wastewater treatment conditions. Second, the study focuses primarily on organic wastewater, and results may vary with industrial or toxic effluents.

Third, environmental factors such as seasonal variations, temperature fluctuations, and long-term system stability were not extensively analyzed. Fourth, scalability issues were not deeply explored due to pilot-scale limitations.

Fifth, the study does not include long-term economic analysis or lifecycle cost assessment of vermifiltration systems.

Despite these limitations, the study provides valuable insights into the effectiveness and potential of vermifiltration as a sustainable wastewater treatment technology.

XIX. Scope for Future Research

Future research can focus on large-scale implementation of vermifiltration systems in urban wastewater treatment plants. Long-term performance studies are required to evaluate system durability and efficiency under varying environmental conditions.

Further research can also explore hybrid systems combining vermifiltration with constructed wetlands or membrane filtration for improved efficiency. Optimization of earthworm species and loading rates can enhance treatment performance.

Additionally, studies on pathogen removal efficiency, heavy metal treatment, and industrial wastewater applications can expand the scope of this technology.

Economic feasibility studies and life cycle assessments are also needed to evaluate cost-effectiveness over time. Finally, policy-oriented research can examine strategies for integrating vermifiltration into national and regional wastewater management frameworks.

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