

REVIEWER'S REPORT

Manuscript No.: IJAR-54096

Title: Zero Liquid Discharge (ZLD) and Sludge Valorization: Dual Pathways for Sustainable Wastewater Management in India

Recommendation:

Accept as it

Rating	Excel.	Good	Fair	Poor
Originality		√		
Techn. Quality			√	
Clarity		√		
Significance		√		

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Date: 29-09-2025

Detailed Reviewer's Report

1. Object of the Work

Evaluate the limitations of current Zero Liquid Discharge (ZLD) practices in India's industrial sectors and explore the potential of sludge valorization—specifically through composting—as a sustainable and economically viable alternative for wastewater and sludge management.

2. Ineffectiveness of ZLD in Real-World Industrial Settings

Despite regulatory mandates by bodies like the CPCB, ZLD systems in industries especially textiles fail to achieve complete wastewater recycling. Operational data indicates only 50–70% water recovery, with 30–50% of effluents often being illegally or unsustainably discharged, undermining environmental goals.

3. High Resource and Operational Burden of ZLD Systems

ZLD technologies, particularly those using thermal evaporators and crystallizers, are energy- and chemical-intensive, with high O&M costs and frequent mechanical failures. These factors make ZLD economically unviable for small- and medium-scale enterprises (SMEs) and environmentally questionable due to large carbon footprints.

4. Compliance-Driven Mindset Undermines Sustainability

Industries often treat ZLD as a regulatory checkbox rather than a sustainable practice. Without incentives, technical support, or flexible policy models, industries prioritize cost-cutting over innovation, resulting in poor implementation and minimal ecological benefit.

5. Sludge Disposal: A Growing but Ignored Problem

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ZLD and ETPs generate large volumes of sludge, much of it classified as hazardous waste. Improper disposal through landfilling or incineration leads to soil, air, and water pollution. Current frameworks lack robust strategies for safe handling or resource recovery from sludge.

6. Sludge Valorization through Composting Shows Promise

Research shows that co-composting textile ETP sludge with organic matter significantly improves its nutrient profile and reduces toxicity. The process transforms sludge into a usable soil amendment, supporting circular economy objectives and reducing disposal costs.

7. Proven Agronomic Benefits of Sludge-Based Fertilizer

Field trials demonstrated that composted sludge outperformed traditional NPK fertilizers, with 13–40% improvements in germination, biomass, and yield across crops like wheat and vegetables. The compost also enhanced soil structure, water retention, and microbial activity.

8. Safety Confirmed, but Monitoring Needed

Laboratory tests confirmed heavy metals (Pb, Cd, Cr) in compost remained below FAO/WHO permissible limits, and no bioaccumulation was detected in plant tissues. However, long-term use and high application rates can cause phytotoxic effects, requiring regular monitoring and dosage optimization.

9. Hybrid Wastewater Treatment Models as a Viable Alternative

A more sustainable solution lies in hybrid models that integrate engineering solutions (ZLD) with nature-based approaches like constructed wetlands, algal ponds, and biofilters. These systems are cost-effective, reduce chemical dependency, and are especially useful for SMEs.

10. Role of Technology and Renewable Energy in Improving ZLD

Adoption of AI/ML tools for predictive maintenance, process optimization, and chemical dosing can improve ZLD efficiency. Integrating renewable energy sources like solar thermal or biomass can reduce operational costs and carbon emissions, making ZLD more sustainable.

11. Policy Reforms and Incentives Are Critical for Scale-Up

To transition from compliance to sustainability, policymakers should:

- Recognize composted sludge as a legitimate agri-input, with quality standards and safety checks.
- Support centralized composting units and decentralized pilot programs.
- Offer financial incentives (grants, tax breaks) and training programs for farmers and industries.
- Encourage cross-sector collaboration among industry, agriculture, and regulatory bodies.

12. Applications of the Work

a) Sustainable Agriculture through Sludge-Derived Fertilizer

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The study demonstrates that composted textile ETP sludge, when properly treated and co-composted with organic matter, can be used as a low-cost, nutrient-rich fertilizer. This has direct applications in:

- Enhancing soil fertility and crop productivity in rural and peri-urban farming communities.
- Reducing dependency on synthetic fertilizers, thereby lowering input costs for farmers and improving long-term soil health.

b) Improved Industrial Wastewater Management Models

The findings support the development of hybrid wastewater treatment systems that integrate sludge valorization with existing ZLD or ETP frameworks. This can be applied to:

- Help industries, especially small- and medium-scale enterprises (SMEs), reduce sludge disposal costs and improve compliance.
- Promote a circular economy approach within industrial ecosystems by converting waste into a resource, thereby aligning with sustainability and climate goals.