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Recycling Construction Waste Aggregates for Sustainable Wastewater Treatment: Water Quality and Leaching Potential

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Abstract **-** This study investigates the potential of using recycled construction demolition waste (CDW) aggregates in biofilters for sustainable wastewater treatment. The experiment assessed the efficiency of natural and recycled aggregates, with batch experiment dosages of 1, 2, and 3 gCDW/mg, in removing pollutants from synthetic wastewater. The water quality analysis revealed that natural aggregates significantly improved chemical oxygen demand (COD), total nitrogen (TN), and phosphate removal, with COD reductions of 24–31%, phosphate removal up to 58%, and TN reductions between 80–82%. Conversely, recycled aggregates demonstrated limited effectiveness, particularly in terms of COD and phosphate removal, with only moderate TN reductions (14–22%). Furthermore, recycled aggregates posed risks of chemical leaching, releasing high levels of calcium, potassium, and sodium, along with trace amounts of potentially toxic elements. These results highlight the importance of carefully selecting aggregates and conducting additional research on pretreatment methods to minimize leaching and improve wastewater treatment performance.

Keywords**:** Biofiltration; Leaching Potential; Recycled Aggregates; Wastewater Treatment

1. Introduction

Sustainable wastewater treatment is increasingly essential as urbanization and population growth place additional pressure on both water resources and solid waste management systems [1]. One innovative approach that integrates resource recovery and waste minimization is the use of recycled construction and demolition waste (CDW) aggregates in biofiltration systems [2]. CDW, primarily composed of concrete, brick, and masonry materials, represents a significant portion of global solid waste [3]. Their potential reuse in environmental applications has garnered attention due to their abundance, low cost, and alignment with the principles of a circular economy [4].

Biofilters, which support microbial communities immobilized on filter media, offer effective biological treatment of wastewater by degrading organic matter and nutrients [5]. Conventional media such as sand and gravel have been widely used in biofiltration systems [6]; however, the substitution with recycled aggregates may provide comparable performance while diverting CDW from landfills [7]. Despite this potential, the leaching behavior of recycled materials, which may release secondary contaminants such as heavy metals and alkali salts into the treated water, remains concerning [8].

Previous studies have demonstrated varying levels of pollutant removal efficiency depending on the type, size, and pretreatment of the aggregates used [9]. While natural aggregates have consistently demonstrated stable performance with minimal leaching [10], recycled aggregates exhibit heterogeneous properties that are influenced by their composition and origin [11]. Moreover, there is limited data on the comparative removal of key wastewater constituents such as chemical oxygen demand (COD), total nitrogen (TN), and phosphates, using recycled versus natural aggregates in controlled biofilter setups [12].

The current research addresses a critical knowledge gap by systematically evaluating the treatment performance and leaching potential of recycled CDW aggregates in lab-scale biofilters treating synthetic wastewater. The study aims to determine the feasibility of using these materials for effective pollutant removal while assessing risks associated with chemical leaching. By identifying optimal aggregate types and dosages, this work contributes to the development of cost-effective and environmentally sustainable treatment systems. The central research problem is whether recycled CDW aggregates can serve as viable biofilter media without compromising water quality due to the release of harmful substances.

2. Methods

This study was conducted using a series of lab-scale biofilters designed to evaluate the pollutant removal efficiency and leaching behavior of natural and recycled construction and demolition waste (CDW) aggregates. The biofilters operated in batch mode and were loaded with either natural aggregates (washed gravel) or recycled CDW aggregates consisting mainly of crushed concrete and masonry debris. All aggregates were sieved to a uniform particle size of 1 cm and rinsed with deionized water before use, without any chemical pretreatment. Three aggregate-to-wastewater dosage ratios were tested: 1 g/mL, 2 g/mL, and 3 g/mL.

Synthetic wastewater was prepared to simulate the typical characteristics of municipal wastewater. It contained approximately 600 mg/L of total organic carbon (TOC), expressed in COD-equivalent terms, 80 mg/L of total nitrogen (TN), 50 mg/L of phosphates (PO_4^{3-}), and 40 mg/L of total suspended solids (TSS). Fresh synthetic wastewater was prepared before each batch experiment.

Water quality analyses were performed on influent and effluent samples to determine the removal of pollutants and assess leaching behavior. TOC and TN were measured using a Shimadzu TOC-LCSN analyzer equipped with a TNM-L module. Phosphates and nitrates were quantified using ion chromatography (IC), specifically a Dionex ICS-6000 system. TSS and dissolved oxygen (DO) were determined using Standard Methods for the Examination of Water and Wastewater.

To assess the leaching potential of the aggregates, treated water samples were analyzed for major cations and trace elements. These included calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}), strontium (Sr), and chromium (Cr), which were measured using inductively coupled plasma mass spectrometry (ICP-MS) with an Agilent 7900 instrument. All measurements were conducted in accordance with appropriate quality control and calibration standards to ensure the accuracy and reproducibility of the data.

3. Results

3.1. Pollutant Removal Efficiency

The performance of the biofilter reactor was evaluated based on the removal of chemical oxygen demand (COD), total nitrogen (TN), and phosphate (PO_4^{3-}) from synthetic wastewater using both natural and recycled aggregates.

Natural aggregates exhibited superior treatment performance across all tested dosages. COD removal efficiencies for 200 g, 400 g, and 600 g (1 g/mL, 2 g/mL, and 3 g/mL dosages) were 31%, 25%, and 24%, respectively. Similarly, phosphate removal increased with aggregate dosage, reaching 55%, 56%, and 58% for the respective dosages. Total nitrogen removal was particularly high, ranging from 80% to 82% across all natural aggregate treatments. These results indicate a consistent trend of enhanced pollutant removal with increasing aggregate mass.

In contrast, recycled aggregates demonstrated significantly lower removal efficiencies. COD and phosphate concentrations showed a slight increase after treatment, while TN removal achieved only 14%, 17%, and 22% for the same increasing dosage levels. These results suggest that recycled aggregates, in their current untreated form, are not effective for COD or phosphate removal and offer only limited nitrogen reduction potential.

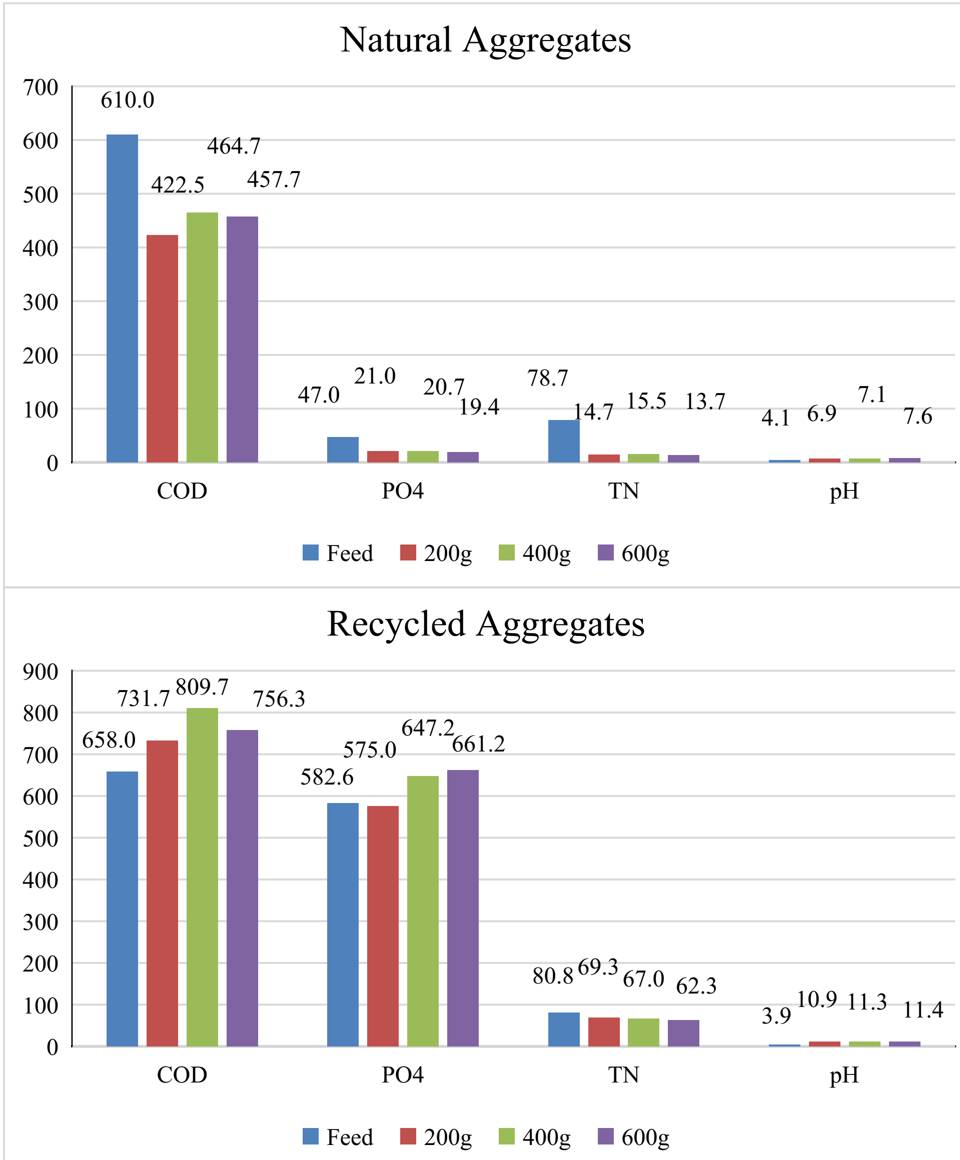

Fig. 1: Bar graph showing COD (mg/L), TN (mg/L), PO_4^{3-} (mg/L) removal for natural and recycled aggregates at 200, 400, and 600 g

3.2. Chemical Leaching Assessment

The chemical leaching behavior of both aggregate types was evaluated by measuring the concentration of major cations and trace elements in the treated water. Natural aggregates introduced only minor changes in water chemistry. Calcium, potassium, and magnesium levels increased modestly, with maximum concentrations observed at 49 mg/L (Ca), 31 mg/L (K), and 14 mg/L (Mg). Sodium concentrations remained low, and no trace elements such as strontium (Sr) or chromium (Cr) were detected.

In comparison, recycled aggregates caused substantial leaching. Calcium concentrations increased to 156, 175, and 179 mg/L for the 200 g, 400 g, and 600 g dosages, respectively. Potassium and sodium levels also rose sharply, reaching 166 mg/L (K) and 455 mg/L (Na) at the highest dosage. Moreover, recycled aggregates introduced trace levels of potentially hazardous elements. Strontium concentrations peaked at 2.2 mg/L, while chromium reached 1.6 mg/L in the effluent.

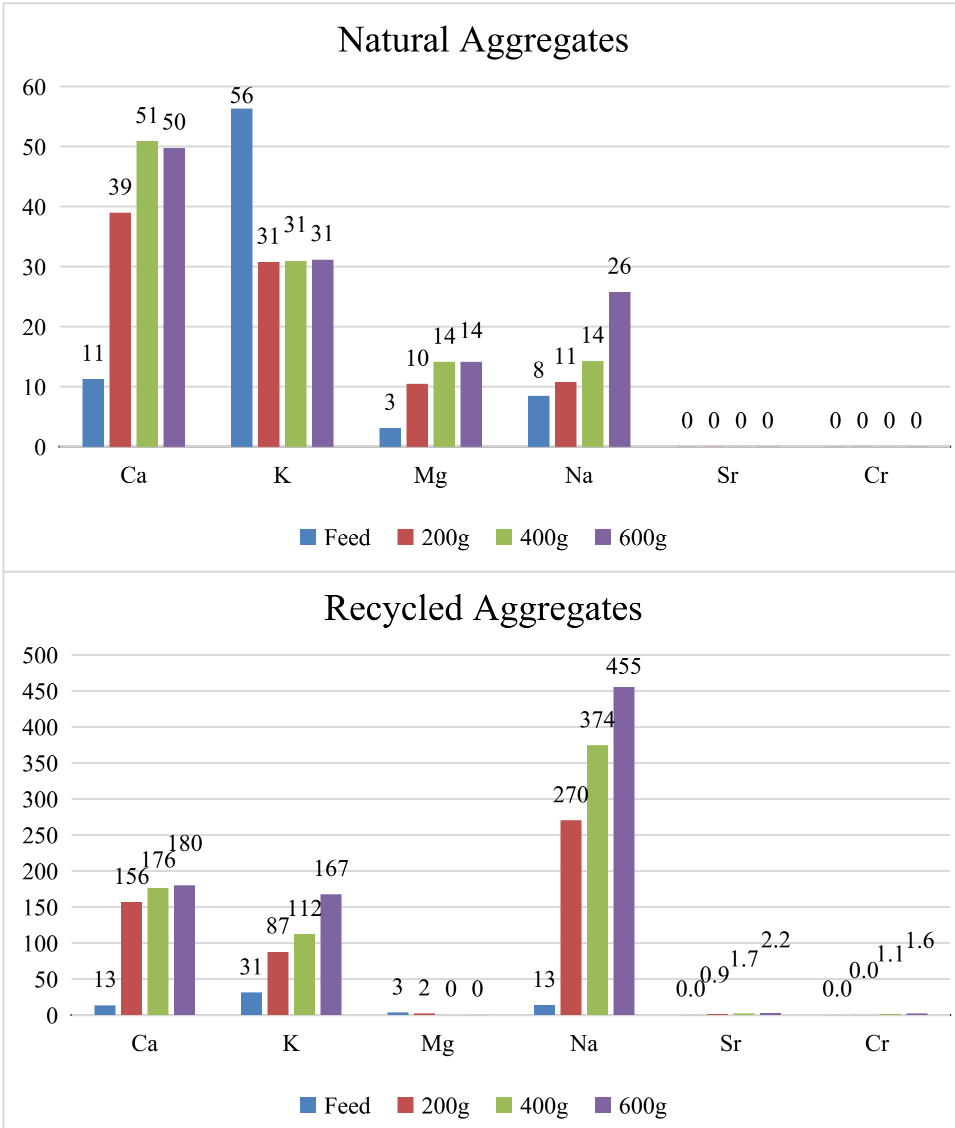

Fig. 2: Bar chart comparing leached Ca, K, Mg, Na, Sr, and Cr (mg/L) for both aggregate types across dosages

4. Discussion

This study provides insights into using CDW as a biofilter material for wastewater treatment. The performance differences between natural and recycled aggregates were evident in terms of pollutant removal and leaching potential.

Natural aggregates consistently demonstrated high removal efficiencies for COD, TN, and phosphate, with performance improving as the aggregate dosage increased. This can be attributed to their stable physical structure, lower porosity, and minimal chemical reactivity, which all support effective microbial colonization and reduce the likelihood of leaching. The consistent trends in pollutant reduction also suggest that the natural aggregates maintained favorable hydraulic conditions throughout the treatment period, allowing sufficient contact time between the wastewater and the bioactive surfaces.

Conversely, recycled aggregates displayed limited capacity for pollutant removal, especially for COD and phosphate. Their relatively better, yet still suboptimal, TN removal may indicate partial biological activity, though not sufficient to meet treatment goals. The observed poor performance could be linked to the heterogeneity and residual contaminants in the recycled materials, which may interfere with microbial activity or inhibit pollutant adsorption.

On the other hand, the elevated leaching from recycled aggregates was concerning. The release of calcium, potassium, sodium, and trace metals such as strontium and chromium indicates secondary contamination. These results highlight that although recycled aggregates align with circular economy principles, their uncontrolled chemical release could undermine treatment objectives and compromise the quality of the effluent. The detection of chromium and strontium, even at low concentrations, is crucial in regulatory contexts where strict limits on heavy metals in effluent are enforced.

From a sustainability and scalability perspective, the use of recycled aggregates in their untreated form appears unsuitable without further processing. Pretreatment techniques, such as washing, chemical stabilization, or encapsulation, should be explored in future studies to reduce the leaching potential while preserving or enhancing pollutant removal capabilities.

This study reinforces the importance of matching aggregate selection to treatment goals and site-specific regulatory constraints. While natural aggregates remain the most reliable choice in the current configuration, the environmental and economic appeal of recycled materials justifies continued research into their safe integration into engineered treatment systems.

5. Conclusion

This study assessed the effectiveness and environmental implications of utilizing natural and recycled construction waste aggregates as biofilter media in a laboratory-scale wastewater treatment system. Natural aggregates demonstrated superior pollutant removal performance, achieving significant reductions in chemical oxygen demand (COD), total nitrogen (TN), and phosphate concentrations. These aggregates also showed minimal chemical leaching, indicating strong compatibility with biofiltration systems and compliance with water quality standards.

In contrast, recycled aggregates exhibited limited treatment efficiency and introduced substantial chemical leaching, including elevated levels of calcium, sodium, and trace contaminants such as chromium and strontium. While their use supports sustainability goals by promoting material reuse, the risk of secondary contamination makes them unsuitable for direct application without prior treatment or stabilization.

The findings validate the potential of using construction aggregates in sustainable wastewater treatment systems, particularly natural aggregates. Future research should focus on developing pretreatment strategies to improve the performance and safety of recycled aggregates, enabling their broader adoption in decentralized or resource-limited treatment contexts. This work contributes to advancing circular economy practices while supporting environmental protection and water quality management.

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References

[1] S. C. Jhansi and S. K. Mishra, "Wastewater treatment and reuse: sustainability options," Consilience, no. 10, pp. 1–15, 2013.

[2] M. J. Whittaker, K. Grigoriadis, M. Soutsos, W. Sha, A. Klinge, S. Paganoni, M. Casado, L. Brander, M. Mousavi, M. Scullin, R. Correia, T. Zerbi, G. Staiano, I. Merli, I. Ingrosso, A. Attanasio, A. Largo, "Novel construction and demolition waste (CDW) treatment and uses to maximize reuse and recycling," Adv. Build. Energy Res., vol. 15, no. 2, pp. 253–269, 2021.

[3] S. Gunasekar, N. Ramesh, and G. Shivani, "Effective utilisation of construction and demolition waste (CDW) as recycled aggregate in concrete construction – a critical review," Int. Res. J. Multidiscip. Technovation, vol. 1, no. 6, pp. 465–469, 2019.

[4] S. Martini, D. Kharismadewi, and Y. R. Ginting, “Biomass potential as an alternative resource for valuable products in the perspective of environmental sustainability and a circular economy system,” in IOP Conf. Ser.: Earth Environ. Sci., vol. 1175, no. 1, p. 012012, May 2023.

[5] K. N. Yogalakshmi, A. Sharma, and S. Mittal, “Biofiltration in wastewater treatment plants: An overview,” in An Innovative Role of Biofiltration in Wastewater Treatment Plants (WWTPs), pp. 171–188, 2022.

[6] Z. Z. Loh, N. S. Zaidi, A. Syafiuddin, E. L. Yong, R. Boopathy, A. B. H. Kueh, and D. D. Prastyo, “Shifting from conventional to organic filter media in wastewater biofiltration treatment: a review,” Appl. Sci., vol. 11, no. 18, p. 8650, 2021.

[7] G. S. D. Reis, M. Quattrone, W. M. Ambrós, B. G. Cazacliu, and C. H. Sampaio, “Current applications of recycled aggregates from construction and demolition: A review,” Materials, vol. 14, no. 7, p. 1700, 2021.

[8] K. M. Tasneem, J. Eun, and B. Nam, “Leaching behaviour of municipal solid waste incineration bottom ash mixed with Hot-Mix Asphalt and Portland cement concrete used as road construction materials,” Road Mater. Pavement Des., vol. 18, no. 3, pp. 687–712, 2017.

[9] J. Yang, Y. Guo, V. W. Y. Tam, A. Shen, X. Qin, J. Tan, J. Zhang, C. Zhang, “Research on the purification efficiency and mechanism for road runoff pollutants in pervious concrete with recycled aggregates,” J. Environ. Manage., vol. 353, p. 120180, 2024.

[10] S. Erdem and M. A. Blankson, “Environmental performance and mechanical analysis of concrete containing recycled asphalt pavement (RAP) and waste precast concrete as aggregate,” J. Hazard. Mater., vol. 264, pp. 403–410, 2014.

[11] A. Diotti, A. P. Galvin, A. Piccinali, G. Plizzari, and S. Sorlini, “Chemical and leaching behavior of construction and demolition wastes and recycled aggregates,” Sustainability, vol. 12, no. 24, p. 10326, 2020.

[12] D. S. Tanmoy, J. C. Bezares-Cruz, and G. H. LeFevre, “The use of recycled materials in a biofilter to polish anammox wastewater treatment plant effluent,” Chemosphere, vol. 296, p. 134058, 2022.