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Preliminary Studies on The Use of Rice Husk As Permeable Reactive Barrier for Heavy Metal Removal from Dumpsite Leachate

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ABSTRACT

This study evaluated the performance of rice husk powder as a permeable reactive barrier (PRB) for the removal of heavy metals from dumpsite leachate using column adsorption experiments. Rice husk with a pH of 6.05, bulk density of 1.8 g/cm³, and water-soluble matter of 9.48% was packed into columns of 200 mm and 400 mm bed depths, and leachate was passed through over 12 days. Results showed that removal efficiency increased with both contact time and bed depth. At 400 mm depth, maximum removal efficiencies after 12 days reached 66% for Cd, 64% for Cu, 62% for Cr, and 60% for Zn, compared to lower values at 200 mm depth (52% for Cd and 49% for Cu, respectively). Fe consistently showed the lowest removal efficiency (25–42%), attributed to its higher concentration (9.126 mg/L) and larger hydrated radius. The adsorption process exhibited time-dependent selectivity, with shifting removal order across sampling intervals. Despite moderate efficiencies (average peak ≈52%), the results demonstrate that rice husk has promising potential as a low-cost, locally available PRB material for leachate treatment, though performance is influenced by some intrinsic characteristics of rice husk.

Keywords: *Rice Husk, Permeable Reactive Barrier, Landfill Leachate, Heavy Metals, Removal Efficiency.*

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I. INTRODUCTION

Landfill leachate constitutes a high concentration of salts, organic matter, and heavy metals. Its migration pollutes soil, groundwater, and surface water. Engineered landfills are therefore designed with leachate collectors for proper treatment and disposal (Nta and Odiong, 2017). However, engineered landfills are not common waste management facilities in developing countries like Nigeria. The common municipal waste management system is the open-pit dumpsite (Ukoha-Onuoha et al., 2026). Open-pit dumpsites are unlined landfills that allow free leachate transport through the soil column, resulting in soil, groundwater, and surface water pollution.

The use of a permeable reactive barrier (PRB) in the path of the leachate plume is an emerging technology to control soil and groundwater pollution (Yin et al., 2017; Kankanige et al., 2019; Jayasundara et al., 2023). PRB is a continuous, in-situ permeable treatment zone designed to intercept and remediate a contaminant plume. PRBs are such that contaminated water passes through them, and contaminants are either immobilized or chemically transformed into less toxic, more readily biodegradable state. A permeable reactive barrier consists of a water-permeable material with specific chemical reactivity towards one or more chemical constituents through mechanisms such as adsorption, ion exchange, oxidation-reduction, or precipitation. Such materials should be inexpensive and readily available in multiple-ton quantities to treat large volumes of leachate (Judith *et al.,* 2003).

One such material is rice husk, an agro-waste commonly found in most parts of Nigeria, Africa's leading producer of rice (Lala et al., 2025). During the 2024/2025 season, Nigeria's milled rice production was reported at 5.23 million metric tons (BusinessDay, 2025). This suggests the abundance of rice husk as an agricultural residue, particularly in the Middle Belt region with active rice milling operations. However, studies have demonstrated the under-exploitation of this agro-waste, despite its abundance, chemical stability, low bulk density, high surface-to-volume ratio, and very minimal cost (Lala et al., 2025). These characteristics, in addition to its renewability, make rice husk a potential material for a permeable reactive barrier for leachate transport. The aim of this study, therefore, is to investigate the suitability of rice husk as a permeable reactive barrier to intercept and treat dumpsite leachate. The specific objectives include: i) to characterize rice husk and open-pit dumpsite leachate, ii) to determine the effect of barrier depth on contaminant removal efficiency.

II. MATERIALS AND METHODS

2.1 Rice Husk and Dumpsite Leachate

Figure 1 shows the rice husk in pellet and powder form (Figure 1A and 1B) used in this study. The rice husk was obtained from Ini Local Government Area, Akwa Ibom State, Nigeria. The collected rice husk was soaked in distilled water to reduce the amount of water-soluble matter and was finally air-dried. The dried material was ground using an electric grinder (Retsch SM 100 Cutting Mill, Retsch GmbH, Germany) and sieved to get the particle size of 0.450 mm to 2 mm (Figure 1a and 1b). The water-soluble matter and pH of the rice husk powder were analyzed in accordance with Dhayabaran *et al*. (2012), while bulk density was determined by the standard container method with Equation 1.

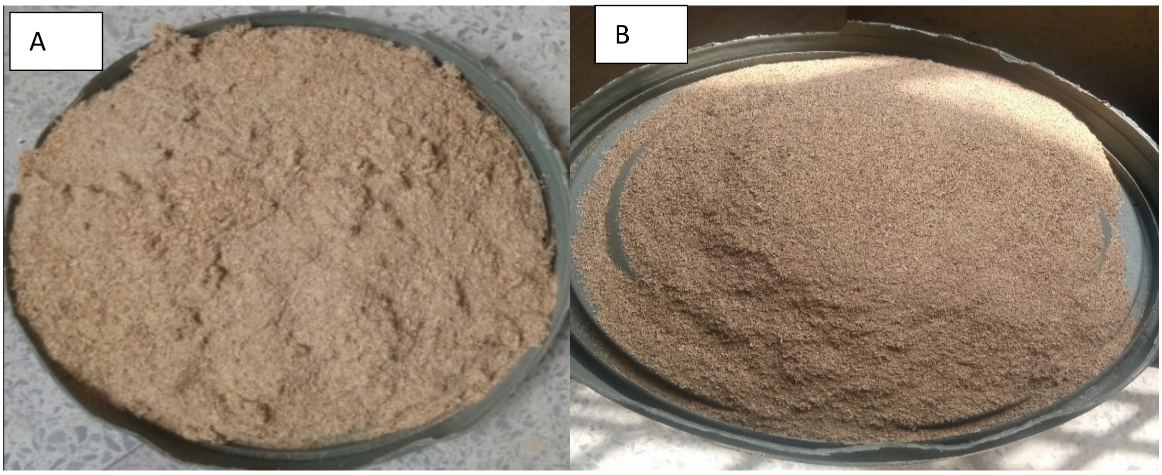

Figure 1: Rice husk

(1)

Landfill leachate was collected from Uyo main refuse dumping site in Akwa Ibom State, Nigeria (Figure 2). The collected leachate was taken to the laboratory and kept in the refrigerator at 4 .

Figure 2 Leachate Sample

Some selected physico-chemical properties of the leachate were analyzed in line with the American Public Health Association (APHA, 1995) standard. The properties include chloride, ammonia, nitrate, Fe, Mn, Zn, Cr, Cu, Cd, and Ni.

2.2 Column Adsorption Experiment

PVC pipes of 250 mm height and 150 mm diameter were used. A perforated plug was fixed at the bottom of the column. The experiment was carried out in 2 sets. First set for an adsorption bed depth of 200 mm and a second set for an adsorption bed depth of 400mm. For each set of experiments, a total of four columns were arranged in parallel as shown in Figure 3. Rice husk was loaded in each column, and leachate was allowed to flow by gravity through the columns at a constant flow rate of 1.157 /sec for 12 days. Treated leachate was collected every 4-day interval for analyses following standard methods as published by APHA (1995). Chemical parameters of raw and treated leachate analyzed include chloride, ammonia, nitrate, Fe, Cr, Cd, Ni, Mn, Pb, and Cu. The removal efficiency of the target pollutants was calculated using Equation 2

(2)

Where:
E = removal efficiency (%)
C_i = influent concentration of the pollutant (mg/l)
C_e = effluent concentration of the pollutant (mg/l)

Figure 3 Experimental Set-up

III. RESULTS AND DISCUSSIONS

3.1 Characteristics of Rice Husk Powder

The characteristics of rice husk powder are displayed in Table 1, with pH indicating slight acidity but within the recommended range of 5.5 – 7.5 (Kumar et al., 2012). The acidity is attributable to the organic content in rice husk. Bulk density and water-soluble matter of rice husk are 1.8 g/cm^3 and 9.48%, respectively, but these values are higher than the typical values of 0.09 – 0.16 g/cm3 for bulk density and 2 – 8% for water-soluble matter (Pode, 2016; Foo and Hameed, 2010). The high bulk density of the rice husk is due to the breaking of the fibrous material into powder. Although this increases the surface area, it also reduces the porosity as tiny particles fill up void spaces (Bansal et al., 2009). Another possible contribution to the high bulk density is moisture content. Moisture content in rice husk enhances particle cohesion that translates into higher bulk density. The high bulk density and high water-soluble matter (9.48%) are consistent with prolonged soaking. Although soaking of rice husk was intended to leach soluble materials, prolonged soaking could have converted insoluble components into water-soluble materials (Mohan et al., 2014).

Table 1 Characteristics of Adsorbents

Parameter	Rice Husk
pH	6.05
Water soluble matter (%)	9.48
Bulk density (g/cm^3)	1.8

3.2 Rice Husk Powder Adsorptive efficiency based on metal properties

Figures 4 and 5 show the removal efficiency of selected heavy metals. It was observed that rice husks selectively adsorbed the metals, and metal adsorption increased with bed depth. For both 200 mm and 400 mm bed depth, the least removed metal was Fe^{2+}, while the most removed varied with time. The least adsorption of Fe^{2+} by rice husk is attributed to its concentration and hydrated radius. Table 2 shows that the concentration of Fe^{2+} in the raw leachate is the highest, and its hydrated radius of 4.3 – 4.8 is larger than that of the other metals except for Mn^{2+} and Cr^{3+} (Nightingale, 1959). Metals with larger hydrated radius have been reported to have higher restrictions in mobility towards and diffusion into adsorption sites, resulting in lower removal efficiency (Fashina and Ilgen, 2026). However, Cr^{3+} with the largest hydrated radius (Table 2) favourably competed with other metals because of its lower concentration and higher charge density that enhanced a stronger electrostatic attraction. The multi-metal system of leachate creates competition among the metals for adsorption sites. According to Yin et al. (2024), selectivity and competition among multi-metals reduce adsorption capacity.

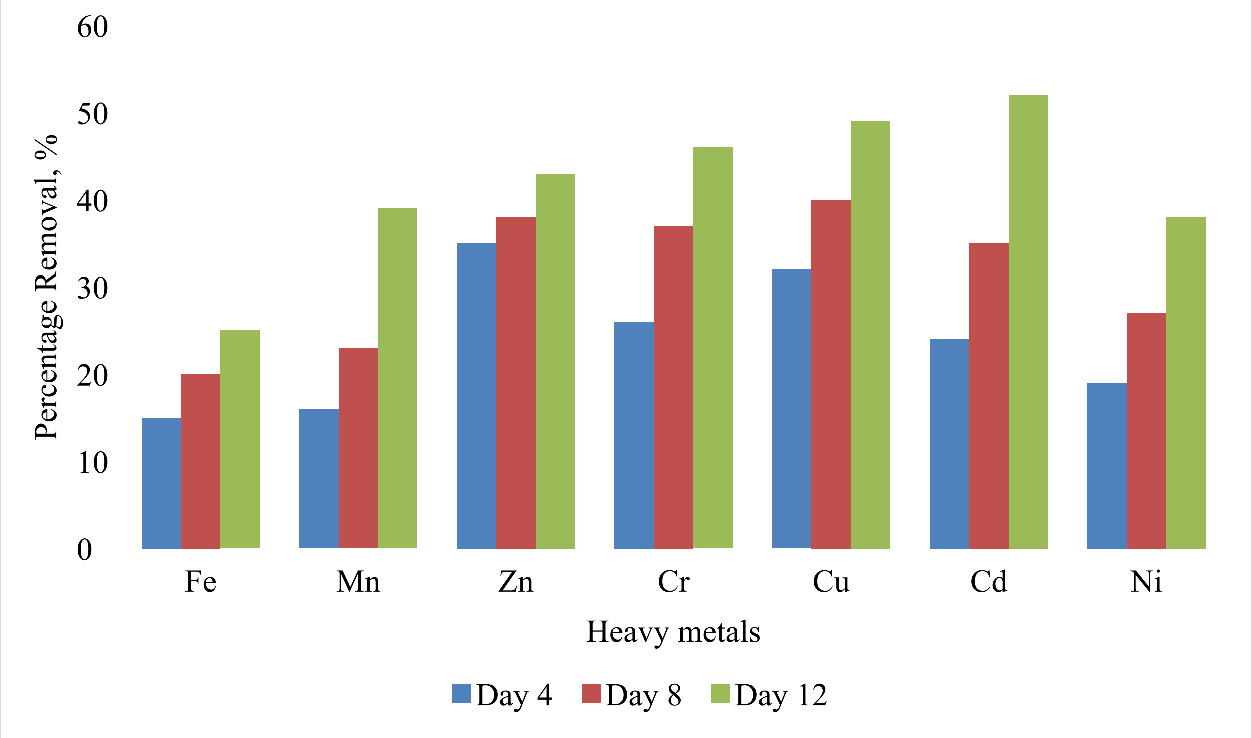

Figure 4: Heavy Metal Removal Efficiency at a Column Bed Depth of 200mm

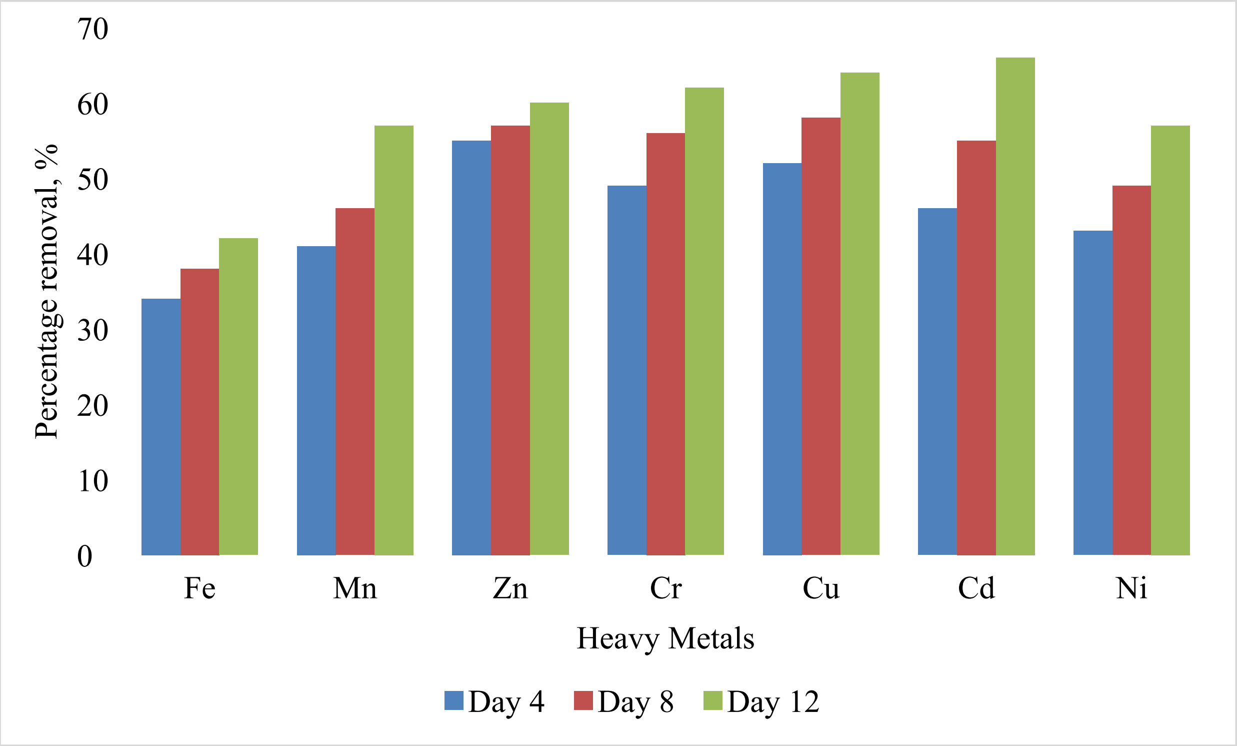

Figure 5: Heavy Metal Removal Efficiency at a Column Bed Depth of 400mm

Table 2: Heavy metal concentration in Leachate and radius

Heavy metals	**Concentration (mg/l)**
Fe	9.126
Mn	3.395
Zn	2.486
Cu	0.72
Cr	0.63
Ni	0.26
Cd	0.071

3.3 Rice Husk Powder Adsorptive efficiency based on systemic factor

Two systemic factors under consideration were column bed depth and porosity of rice husk. 200 mm and 400 mm bed depths were used in the treatment of the leachate. For both 200 mm and 400 mm bed depth, Zn, Cu, and Cd were the most removed for the initial, mid, and final phases, which were taken at 4, 8, and 12 days, respectively. It was observed that the removal percentage increased with column bed depth. This is consistent with previous works on adsorption (Yahya et al., 2020; Abbas and Kebria, 2023). The removal percentage increased from 35% to 55% for Zn, 40% to 58% for Cu, and 52% to 66% for Cd. These removal efficiencies are lower than other works on metal adsorption (Yin et al., 2017; Li and Liu, 2022, Venkat et al., 2022) and are associated with the adsorbent porosity. Rice husk with a bulk density of 1.8 g/cm^3 is 91% higher than the higher band width of the typical bulk density of rice husk (0.09 – 0.16 g/cm^3). Bulk density of adsorbents is inversely related to porosity (Georgewill et al., 2026). This explains that, with such high bulk density, porosity could have been low, resulting in potentially lower adsorption efficiency.

3.4 Time Dependence of Selective Adsorption

Selective adsorption for metals was time-dependent (Figures 4 and 5). The time dependence resulted in three different selectivity orders at the initial phase of the adsorption process, which was the first four days. As the adsorption process progressed into the second phase, which is the 8th day, the selectivity order changed to . Further progression into the third and final four-day interval, the selectivity order became . These selectivity orders are slightly different from the typical selectivity order of as reported by Mohan et al. (2014). The selective order of the initial stage sample showed Zn ahead of Cu and Cd, while the mid stage showed Zn ahead of Cd only, and the final stage showed Cd ahead of Cu. This deviation from the typical selectivity order may have been due to system-specific factors having a greater influence over metal properties. According to Mohan et al. (2014), selective adsorption arises because of the different affinities of heavy metals for adsorption sites. Metals with higher charge density are more strongly adsorbed than monovalent ions. However, speciation of heavy metals could lead to a change in the affinity and binding strength of heavy metals, which could lead to a change in the sequence. On average, the highest removal efficiency is 52%, which is lower than some other biosorbents

IV. Conclusion

Rice husk possesses significant potential as a low-cost and readily available reactive material for permeable barriers in landfill leachate management. Its ability to selectively adsorb heavy metals highlights its suitability for in-situ treatment systems, particularly in regions where conventional engineered landfills are limited. Although performance is influenced by factors such as bed depth, porosity, and competitive interactions among contaminants, the findings reinforce the viability of rice husk as a sustainable option for mitigating groundwater and soil pollution from dumpsites.

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