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Feasibility of Rice Husks Adsorption for Removal of Lead and Zinc from Contaminated Wastewater

Leopord Sibomana Leonard[1], Nicholaus Mwageni[2] and Ailen Kakiko[3],

ABSTRACT
Tanzania, like other parts of the world faces a challenge of environmental contamination from heavy metals due to untreated or partially treated industrial wastewater. Although previous studies have demonstrated the effectiveness of agricultural wastes in heavy metals removal from wastewater, but still there remains a limited understanding on the use of rice husks. This study aimed to determine the optimum conditions in removing lead and zinc from wastewater using rice husks. A series of batch experiments were conducted, varying pH, particle size, and adsorbent dose. Agitation at 210 rpm for 24 hours was employed to enhance adsorption. Lead and zinc ions were measured by Atomic Absorption Spectrophotometer. Analysis was done by One-way ANOVA. The results showed that the highest removal efficiencies were at pH of 6.4, particle size of 0.8 mm and adsorbent dosage of 10 g, achieving 96% Pb and 95% removals. Adsorption capacities were 0.12 mg g^{-1} for Pb and 0.19 mg g^{-1} for Zn. However, ANOVA results indicated no statistically significant differences in removal efficiencies among the tested parameters ($p > 0.05$). Rice husks demonstrated potential as effective and low-cost adsorbents for removing both lead and zinc from contaminated wastewater, highlighting their potential for wastewater treatment applications.

Key words: Adsorption; Agro-wastes; Heavy metals, Wastewater Treatment

INTRODUCTION

Lead and Zinc are toxic heavy metals that persist in the environment and bioaccumulate in food chains posing a threat to human health (Morais *et al*., 2012). Lead is a high-priority pollutant which causes health effects including microcytic anaemia resulting from ineffective synthesis by inhibiting production of porphobilinogen synthase and ferro chelatase enzymes, preventing porphobilinogen formation and the incorporation of iron into protoporphyrin IX (Vijayakumar *et al.,* 2012). Zinc though essential for growth and development in animals, plants as well as micro-organisms can result to gastro-intestinal effects, immunological and lymph reticular effects, cardiovascular effects, carcinogenic effects along with neurotoxicity at higher levels *(Sankhla et al.*, 2019). Lead and Zinc enter

[1] Leopard Sibomana is a member of academic staff at the School of Engineering and Environmental Studies (SEES), Ardhi University P.O.BOX 35176, Dar Es Salaam, Tanzania. His email address is leopord.leonard@aru.ac.tz, https://orcid.org/0000-0003-4072-5711
[2] Nicholous Mwageni is a member of academic staff at the School of Engineering and Environmental Studies (SEES), Ardhi University P.O.BOX 35176, Dar Es Salaam, Tanzania. His email address is nicholous.mwagen@aru.ac.tz
[3]Ailen Kakiko is a member of academic staff at the Department of Community Development, Tengeru Institute of Community Development P.O.BOX 1006 Arusha, Tanzania

the environment through both natural (e.g. volcanic activity and natural weathering of the earth's crust) and anthropogenic pathways including industrial discharge, mining, urban run-off, effluents from sewerage systems and agricultural activities (Leonard and Mkumbo, 2025; Jaishankar *et al.*, 2014). Industrial activities, in urban areas like Dar es Salaam, Tanzania have been commonly identified as the main cause of heavy metal contamination. Effluents from industries in Dar es Salaam were found with high concentrations of lead and zinc exceeding Tanzania standards of 0.1mg/L and 5 mg/L respectively (Kihampa, 2016). Therefore, effective removal of these metals from wastewater prior to discharge into the environment is essential to protect human health, aquatic life and the environment (Fu & Wang, 2011).

Several conventional methods have been employed in removal of heavy metals from contaminated water, including physical (screening, aeration, flocculation and skimming), chemical (chlorination, ozonation, coagulation and ion exchange) and biological treatments (activated sludge, oxidation ponds and bio-adsorption) (Al-Qodah *et al*., 2017). However, bio-sorption has proved to be among the most efficient and cost-effective methods, because of its low cost of operation and higher recovery rate of heavy metals (Sulaymon, 2014). Bio-sorption involves the use of biomass or natural substrates such as agricultural residues, forestry waste products, microorganisms, casein and sugar beet pulp. Biosorption has stood out to be one of the most practical, economic, effective and environmentally sustainable method for remediation of wastewater compared to other conventional and commercial methods for removal of heavy metals from wastewater (Saini *et al*., 2020). Rice husks contain cellulose, hemicelluloses, lignin, and silca-rich ash and crude protein at 35%, 25%, 20%, 17% and 3% respectively associated with many chelating ligands and functional groups including hydroxyl, carboxyl, methoxy, and phenolic groups capable of binding heavy metal ions through ion exchange, complexation, and electrostatic attraction mechanisms (Kordi *et al*., 2024; Gupta *et al*., 2022; Mutuku, 2019). The adsorption efficiency of biosorbents is strongly influenced by solution pH, adsorbent particle size, and adsorbent dosage because these parameters directly affect surface charge characteristics, active-site availability, and mass transfer processes (*Kordi et al*., 2024).

Tanzania has experienced significant growth in rice production in recent years and is currently the second-largest rice producer in Eastern and Southern Africa after Madagascar (Bakari *et al*., 2023) During the 2018/2019 cropping season, national rice production was estimated at approximately 3.2 million metric tonnes (Bakari *et al*., 2023). This expansion has resulted in the generation of substantial quantities of rice husk (RH), a major by-product of rice milling that constitutes approximately 20 - 35% of the total weight of paddy rice (Bakari *et al*, 2023; Kordi *et al*., 2024). Consequently, an estimated 0.6 - 1.1 million tons of RH are produced annually in Tanzania. Despite its potential as a valuable biomass resource, rice husk is largely underutilized, with only about 17% being put to productive use (Bakari *et al*., 2023). The remaining quantities are commonly disposed of through open dumping or uncontrolled burning, practices that contribute to environmental degradation, air pollution, and associated public health risks (Luhwago *et al*., 2023). Although several studies have reported the effectiveness of agricultural residues in heavy metal removal, limited information exists regarding the optimization of these parameters for rice husks under conditions representative of wastewater generated in Tanzania. Therefore, this study

investigated the influence of pH, particle size, and adsorbent dosage on the removal efficiency of lead and zinc ions using rice husks as a low-cost biosorbent.

MATERIALS AND METHODS

Materials collection and preparation

The material used in the removal of lead and zinc from contaminated water was rice husks while synthetic wastewater with lead and zinc ions was prepared at Ardhi University in the School of Engineering and Environmental studies laboratory.

Adsorbent collection and preparation

Rice husks were collected from a rice milling facility at Tandale market, Kinondoni District in Dar es Salaam, Tanzania. They were then washed using deionized water and open dried under the sun for 48 hours so that they can be free from moisture. The husks were then cut into small pieces and then grinded to achieve different sizes to enhance their adsorption capacities.

Preparation of lead and zinc synthetic water

Stock solution was prepared by dissolving lead nitrate (Pb $(NO_3)_2$) and zinc nitrate (Zn $(NO_3)_2$) salts where by 0.057g of Pb $(NO_3)_2$ and 0.478g of Zn $(NO_3)_2$ was dissolved in 7 litres of distilled water to prepare synthetic water with concentration of 5mg/L and 10mg/L of lead and zinc ions respectively. The solutions were simulated with reference to wastewater which was collected from NIDA textile industry for adsorption isotherm. Solution pH was adjusted using 0.1 M HCl and 0.1 M NaOH prior to adsorption experiments and monitored throughout the adsorption period. At highly alkaline conditions (pH 11), precipitation of metal hydroxides may occur, potentially contributing to apparent removal efficiency. Therefore, removal observed under strongly alkaline conditions may represent a combination of adsorption and precipitation mechanisms.

Determination of physicochemical characteristics of rice husks.

The physical chemical characteristic of rice husks that was determined in this study was pH and ash content. The fiber content of the husks (83%) was adopted from literature (Shamsollahi and Partovinia (2019).

pH determination

The pH of rice husks was measured to determine the amount of acid and base needed for adjustment of the sample to the desired pH range. Rice husks were both grinded into powder form, mixed with distilled water in separate beakers and the mixture stirred. The pH of each mixture was measured by a pH meter (Combo by HANNA-CHANNA instrument Woonsocket RI USA made in Romania).

Ash content

The ash content of rice husks was determined using the loss on ignition method described by (AOAC, 2000). Crucibles were cleaned, dried at 105℃, and weighed empty. The rice husk samples were then added, weighed and dried in an oven at 105℃ for 24 hours to determine their dry weight. The dried samples were then burned in a muffle furnace at

562℃ for 2 hours. After cooling, the crucibles were weighed to calculate the ash content using equation 1

$$\text{Ash content (\%)} = \frac{W4-W1}{W3-W1} \times 100 \quad \text{..... Equation 1}$$

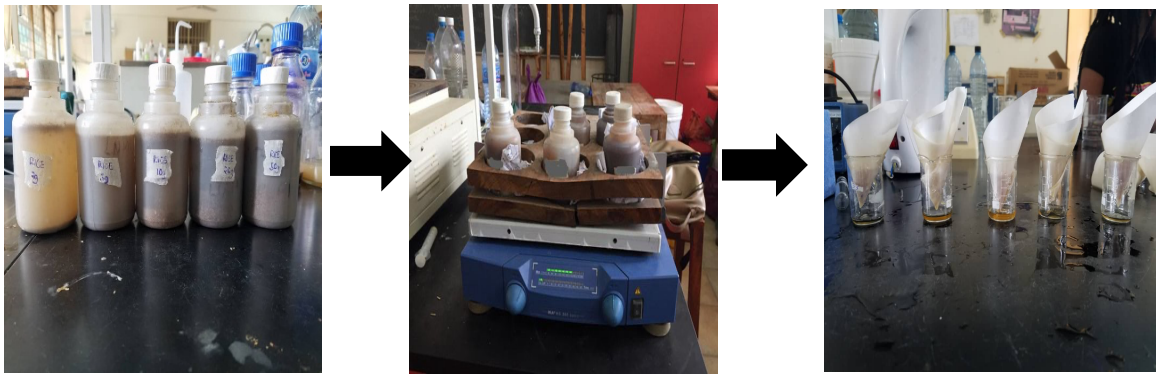
Where: W_1 represents the weight of empty crucible in grams, W_3- weight of crucible with sample dried at 105℃ in grams and W_4- weight of crucible with ash after dried at 562℃ in grams

Fiber content

The fibre content i.e. content of lignin, cellulose and hemicellulose was according to Lata and Samadder in 2014.

Experimental design

Batch experiments were conducted to study the effect of pH, dosage and particle size of the husks on the removal efficiency of lead and zinc ions from contaminated water was studied by varying one parameter while keeping others constant. The bottles were continuously agitated in the shaker at 210 rpm for 24 hours to ensure contact between the adsorbent surface and lead and zinc ions until equilibrium was reached. After settling, the mixture was filtered using 0.45µm Munktell Swedish filter paper then the concentration of lead and zinc ions in the filtrate was measured by Atomic Absorption Spectrophotometer (AAS).



Samples before shaking | Samples in the shaker | Filtration of samples

Figure 1: Experimental design

Quality Assurance and Quality Control (QA/QC)

All adsorption experiments were conducted in triplicate to ensure reproducibility and reliability of results. Analytical-grade lead nitrate and zinc nitrate reagents (≥ 99% purity) were used for synthetic wastewater preparation. Prior to analysis, the Atomic Absorption Spectrophotometer was calibrated using certified standard solutions prepared at multiple concentration levels. Instrument performance was verified using calibration blanks and quality control standards. All glassware was acid-washed and rinsed with deionized water

before use. Blank samples and duplicate analyses were included during laboratory measurements to minimize analytical uncertainties.

Determination of effect of dose on removal of lead and Zinc ions from contaminated water

The effect of dose on removal of lead and zinc ions from contaminated water was established by taking 200 mL of contaminated water containing 6.414 mg/L of lead and 10.08 mg/L of zinc at a known pH, which was treated with different doses of rice husks of 0.8 mm particle size independently. The concentration to mass ratios of 1:5, 2:4, 3:3, 4:2 and 5:1 was used, with rice husks doses of 50g, 20g, 10g, 5g and 2g to determine how the number of husks affects the removal efficiency of lead and zinc.

Determination of effect of pH on removal of lead and Zinc ions from contaminated water

The effect of pH on removal of lead and zinc ions from contaminated water was established by taking 200 mL of contaminated water containing 6.414 mg/L of lead and 10.08 mg/L of zinc which was treated with 50 g of rice husks of 0.8 mm particle size independently. The pH levels were adjusted to 3.0, 5.3, 6.4, 9.0 and 11.0 to create acidic, less acidic, near neutral, less alkaline and highly alkaline condition so as to determine how pH levels influence the removal of lead and zinc ions from contaminated water.

Determination of effect of particle size on removal of lead and Zinc ions from contaminated water

The effect of particle size on removal of lead and zinc ions from contaminated water was established by taking 200 mL of contaminated water containing 6.414 mg/L of lead and 10.08 mg/L of zinc at a known pH was treated with 50g of rice husks independently. Different particle sizes of 0.8 mm, 1.2 mm, 1.8 mm 2 mm and 4 mm were tested in sampling bottles to determine how the particle size of rice husks impacted the removal efficiency of lead and zinc.

Adsorption capacity;

The adsorption capacity of rice husks was calculated using equation 2.

$$Qe = (Co - Ce) * (V/M) \quad \text{..... Equation 2}$$

Removal Efficiency

The efficiency of rice husks in removing lead and zinc ions from contaminated water was determined using equation 3.

$$\text{Removal efficiency (\%)} = \frac{Co-Ce}{Co} \times 100\% \quad \text{..... Equation 3}$$

Where: $Q_{e=}$ Amount of lead and Zinc ions adsorbed in milligram per liter, $C_{o=}$ Initial concentration of lead and Zinc ions in milligram per liter, $C_{e=}$ Concentration of lead and Zinc ions in solution at equilibrium in milligram per liter, V = Volume of waste water used in litters and M= Mass of rice husks in grams

Data analysis

Analysis of variance (ANOVA) was used to determine whether solution pH, rice husk particle size, and adsorbent dosage had significant effects on the removal efficiencies of lead (Pb) and zinc (Zn). All experiments were conducted in triplicate (n = 3), and the results are presented as mean ± standard deviation (SD). The error bars in the figures represent one standard deviation from the mean, indicating the variability among replicate measurements. The ANOVA was performed using Microsoft Excel at a significance level of $\alpha = 0.05$. The statistical significance of each factor was evaluated using the p-value, F-value, and F-critical value. A factor was considered to have a significant effect on Pb and Zn removal efficiency when the p-value was less than 0.05 and the calculated F-value was greater than the F-critical value. Conversely, a p-value greater than 0.05 and an F-value lower than the F-critical value indicated that the factor did not significantly influence the removal efficiency.

Before conducting ANOVA, the assumptions of independence of observations, normality of residuals, and homogeneity of variances were considered. The independence assumption was satisfied through the use of separate experimental runs for each treatment condition. However, because the experiments were conducted with a small replication size (n = 3), the assessment of normality and variance homogeneity was interpreted with caution. Where possible, normality of residuals was evaluated using tests such as the Shapiro–Wilk test, while homogeneity of variances was assessed using Levene's test.

The relatively small sample size (n = 3) provides limited statistical power; therefore, the findings should be interpreted as indicative of treatment effects rather than definitive evidence. Increasing the number of experimental replicates in future studies would improve confidence in the statistical conclusions and provide stronger validation of the observed effects.

RESULTS AND DISCUSSION

Physicochemical Properties of Rice Husks

The physicochemical characteristics of rice husks were evaluated to determine their suitability as an adsorbent for removing lead (Pb^{2+}) and zinc (Zn^{2+}) ions from contaminated water. The adsorption performance of lignocellulosic materials is largely governed by surface chemistry, pore structure, mineral composition, and the interactions between metal ions and functional groups present on the adsorbent surface (Babel & Kurniawan, 2003; Demirbas, 2008; Foo & Hameed, 2010). The physiochemical characteristics of the rice husks are presented hereunder;

pH of Rice Husks

The pH of the rice husks was 6.16, indicating that the material is nearly neutral. This characteristic is advantageous for heavy metal adsorption because solution pH strongly influences adsorption mechanisms through proton competition, surface charge development, and electrostatic interactions (Foo & Hameed, 2010; Fu & Wang, 2011). At low pH, the concentration of hydrogen ions (H^+) is high, resulting in protonation of surface functional groups such as hydroxyl (-OH), carboxyl (-COOH), and phenolic groups (Ho & McKay, 1999). The protonated surface acquires a positive charge, which competes directly

with Pb^{2+} and Zn^{2+} ions for available adsorption sites and creates electrostatic repulsion between the adsorbent surface and metal cations. Consequently, adsorption efficiency decreases (Fu & Wang, 2011).

As the pH approaches neutrality, proton competition is reduced and many acidic functional groups become deprotonated, producing negatively charged sites capable of attracting positively charged Pb^{2+} and Zn^{2+} ions through electrostatic attraction, surface complexation, and ion-exchange mechanisms (Foo & Hameed, 2010; Demirbas, 2008). Therefore, the measured pH of 6.16 is favourable for adsorption because it promotes stronger interactions between heavy metal ions and the rice husk surface. Furthermore, the pH remains below the range where lead and zinc hydroxides readily precipitate. This suggests that heavy metal removal is expected to occur predominantly through adsorption rather than precipitation phenomena, allowing the adsorption capacity of rice husks to be evaluated without significant interference from chemical precipitation (Fu & Wang, 2011; WHO, 2022).

Ash Content of Rice Husks

The ash content of the rice husks was 15.20%, which is comparable to the 17.1% reported by Lata and Samadder (2014). Ash consists primarily of inorganic minerals, particularly silica, together with oxides of potassium, calcium, magnesium, and other trace elements (Lata & Samadder, 2014; Kalapathy *et al*., 2000). The relatively high ash content indicates that rice husks possess a significant amount of silica-rich material, which contributes additional hydroxyl groups capable of interacting with heavy metal ions (Kalapathy *et al*., 2000). These mineral components provide extra adsorption sites through surface complexation and ion exchange, thereby enhancing adsorption capacity (Demirbas, 2008).

In addition, the porous silica framework contributes to an increased specific surface area, exposing more active adsorption sites to metal ions. A larger surface area generally increases adsorption capacity because more binding sites become available for Pb^{2+} and Zn^{2+} ions. The porous structure also facilitates pore diffusion, enabling metal ions to penetrate into the internal pores of the adsorbent where additional adsorption occurs (Babel & Kurniawan, 2003). Consequently, the ash content obtained in this study suggests that rice husks possess favourable mineral characteristics for heavy metal removal (Foo & Hameed, 2010). The slight variation between the present study and previous findings may be attributed to differences in rice variety, soil characteristics, climatic conditions, harvesting practices, and analytical procedures (Lata & Samadder, 2014).

Fibre Content of Rice Husks

Rice husks are predominantly composed of cellulose, hemicellulose, and lignin, with fibre content reported to be approximately 83% (Lata & Samadder, 2014). These lignocellulosic polymers contain abundant hydroxyl, carboxyl, methoxy, and phenolic functional groups that serve as active adsorption sites for heavy metal ions (Demirbas, 2008; Foo & Hameed, 2010). Heavy metal adsorption by rice husks occurs primarily through surface complexation, ion exchange, and electrostatic interactions between these functional groups and Pb^{2+} and Zn^{2+} ions (Babel & Kurniawan, 2003). The hydroxyl and carboxyl groups

donate electron pairs that form coordination bonds with metal ions, resulting in stable surface complexes (Fu & Wang, 2011).

High fibre content also contributes to the development of a porous internal structure, which increases the effective surface area available for adsorption. The interconnected pore network enhances intraparticle (pore) diffusion, allowing metal ions to migrate from the external surface into the interior adsorption sites until equilibrium is achieved. This internal diffusion process increases overall adsorption capacity and improves the efficiency of metal removal (Ho & McKay, 1999; Foo & Hameed, 2010). Therefore, the high lignocellulosic composition of rice husks indicates that the material possesses numerous chemically active sites and a favourable pore structure, making it an effective low-cost adsorbent for the removal of lead and zinc from contaminated water (Demirbas, 2008; Fu & Wang, 2011).

The effect of pH, particle size and dose on removal of lead and zinc ions from contaminated water using rice husks

Effect of solution pH on removal efficiency of zinc and lead.

The removal efficiency of zinc increased with pH from 76% to 95% at pH of 3.0 to 6.4 but decreased at higher pH levels from 95% to 79% at pH of 6.4 to 11.0, as shown in Figure 2. As for lead, the removal efficiency increased with pH from 86% to 94% at pH of 3.0 to 6.4, but also started decreasing at higher pH levels, from 94% to 87% at pH of 6.4 to 11.0, as shown in the same figure. Therefore, maximum removal of both zinc and lead was attained at pH of 6.4 which is near neutral. These results align with studies done by Natamba (2018), which found maximum copper removal at pH 7, and Arnepalli & Gandhi (2015),who explained that low pH hinders adsorption due to proton competition, while high pH inhibits adsorption due to hydroxide ion complexation.

In addition to that, the F value, F critical and p-value for removal of zinc and lead from contaminated water using rice husks at different solution pH using one-way ANOVA were 2.80536, 5.317655 and 0.132481 respectively. From the ANOVA test it was observed that F critical was greater than F value for the significance level selected i.e. 0.05. But also, p-value was greater than alpha (0.05), which revealed that solution pH had no significant impact on removal efficiency of zinc and lead from the solution. This proved that all pH values tested were significantly equally effective in removal of zinc and lead ions from the contaminated water.

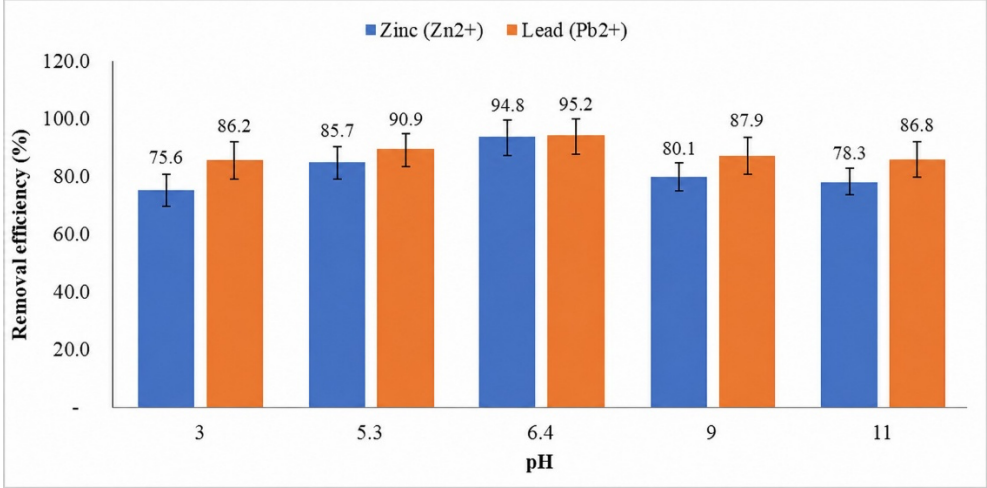


Figure 2: Effect of pH on removal of zinc and lead

Effect of particle size of rice husks on removal efficiency of Zinc

The removal efficiency of both zinc and lead decreased with increasing particle size, from 85% to 59% for zinc and from 94% to 82% for lead (particle size 0.8 mm to 4 mm), as shown in Figure 3. Smaller particle sizes of rice husks provided a larger surface area and more active sites for zinc and lead ions to be adsorbed compared to larger particle sizes leading to higher removal efficiency of both zinc and lead ions from the contaminated water. One-way ANOVA, revealed that particle size of rice husks had no significant effect on the removal of zinc and lead ions from the solution. The analysis showed that, the F value, F critical and p-value for removal of zinc and lead from contaminated water using rice husks at different particle sizes were 3.1526; 5.317655 and 0.113719 respectively. The F critical was greater than F value for the significance level selected i.e. 0.05. But also, p-value was greater than alpha (0.05), which proved that the particle sizes of rice husks used did not significantly impact the removal efficiency of zinc and lead ions from the solution. The results prove further that using rice husks for removal of Zinc and Lead is a cost-effective intervention for wastewater management.

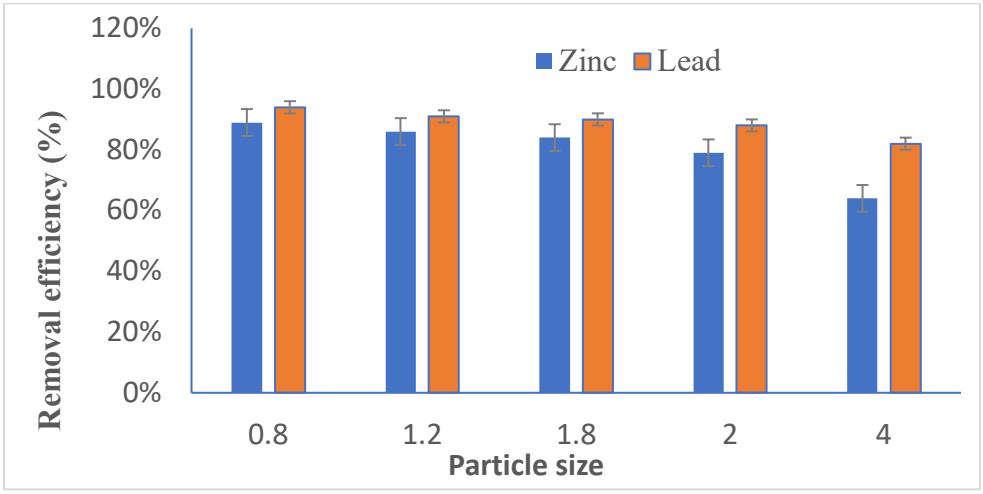


Figure 3: Effect of particle size on removal of zinc and lead

Effect of dose of rice husks on removal efficiency of Zinc and Lead

The removal efficiency of zinc and lead increased as the dose of rice husks was increased from 2 g to 10 g, reaching 95% for zinc and 96% for lead. However, as the dose increased further from 10g to 50g, the removal efficiency declined to 67% and 69% for zinc and lead respectively as shown in Figure 4. These results align with a 2018 study done by Natamba, which found that the removal efficiency of copper increased at moderate doses but decreased at higher doses due to limited active binding sites and equilibrium between adsorbent and adsorbate.

One-way ANOVA showed that the dose of rice husks had no significant effect on the removal of zinc and lead ions from the contaminated water. The F value, F critical and p-value for removal of zinc and lead from contaminated water using different doses of rice husks were 0.094118, 5.317655 and 0.76684 respectively. From the ANOVA test it was observed that F critical was greater than F value for the significance level selected i.e. 0.05. But also, p-value was greater than alpha (0.05), which proved that doses of rice husks had no significant impact on removal efficiency of zinc and lead from the contaminated water.

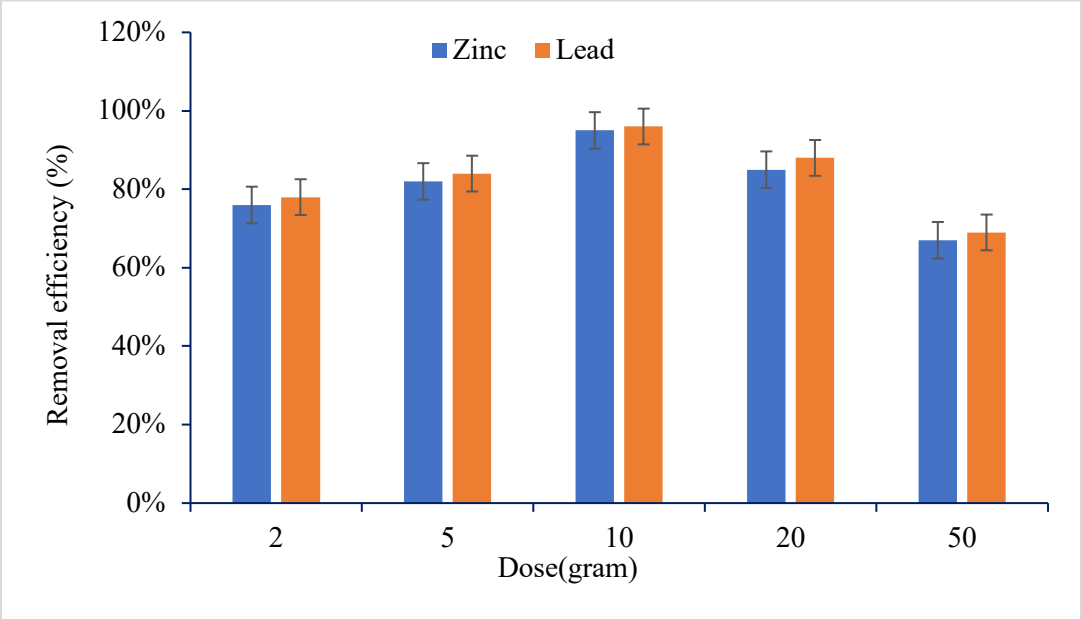


Figure 4: Effect of dose on removal of zinc and lead

Practical applicability of use of rice husks in treatment of wastewater

Heavy metal pollution remains a major environmental concern in Tanzania due to the discharge of untreated or inadequately treated industrial wastewater from mining, textile, electroplating, metal finishing, battery manufacturing, and agro-processing industries. These effluents often contain toxic metals such as lead (Pb), cadmium (Cd), arsenic (As), and zinc (Zn), which are non-biodegradable and can accumulate in aquatic ecosystems and the food chain, posing significant risks to human health and biodiversity (Fu & Wang, 2011; United Republic of Tanzania, 2021; World Health Organization (WHO), 2022).

Findings of this study indicate that rice husks have considerable potential as an inexpensive and environmentally friendly adsorbent for heavy metal removal. Their adsorption capacity

is attributed to the abundance of lignocellulosic polymers and silica, which provide hydroxyl, carboxyl, phenolic, and silanol functional groups capable of binding metal ions through electrostatic attraction, ion exchange, and surface complexation. Furthermore, the porous structure of rice husks enhances the specific surface area available for adsorption and facilitates intraparticle (pore) diffusion of metal ions to internal adsorption sites (Babel & Kurniawan, 2003; Foo & Hameed, 2010; Demirbas, 2008). The optimization of pH, adsorbent dosage, and particle size observed in this study provides valuable information for designing adsorption systems. Operating near neutral pH minimizes proton competition for adsorption sites, while reducing particle size increases the available surface area and decreases diffusion resistance. Similarly, increasing adsorbent dosage increases the number of active adsorption sites until equilibrium is reached, beyond which further dosage increases provide little additional benefit due to site overlap and particle aggregation (Foo & Hameed, 2010; Ho & McKay, 1999).

Despite these advantages, several practical limitations should be considered before large-scale industrial application. Raw rice husks generally possess lower adsorption capacity and slower adsorption kinetics than commercially produced activated carbon because of their lower specific surface area and fewer accessible micropores. Their adsorption performance may also decline in real industrial wastewater containing multiple competing metal ions, suspended solids, oils, organic matter, and fluctuating pH, which can occupy active adsorption sites and reduce metal uptake (Babel & Kurniawan, 2003; Fu & Wang, 2011). Another important consideration is the regeneration and disposal of spent rice husks after adsorption. Once saturated with heavy metals, the adsorbent becomes hazardous waste that cannot be disposed of indiscriminately. Chemical regeneration using dilute acids or alkalis may restore part of the adsorption capacity; however, repeated regeneration cycles can degrade the lignocellulosic structure and reduce adsorption efficiency. Where regeneration is not economically feasible, spent rice husks should be stabilized or disposed of in accordance with hazardous waste management regulations to prevent secondary environmental contamination (Foo & Hameed, 2010; UNEP, 2015).

Scaling the adsorption process from laboratory to industrial level also presents technical challenges. Continuous-flow adsorption columns require optimization of hydraulic loading rate, empty-bed contact time, pressure drop, and breakthrough characteristics, which often differ from batch experimental conditions. In addition, industries would require a reliable supply of rice husks with consistent quality, standardized particle size, and appropriate pre-treatment to ensure reproducible adsorption performance (Crini & Lichtfouse, 2019; Foo & Hameed, 2010). From an economic perspective, rice husks offer a significant advantage because they are an abundant agricultural by-product that requires minimal procurement cost compared with activated carbon. Although activated carbon generally exhibits higher adsorption capacity, faster adsorption rates, and greater regeneration efficiency, its relatively high production and regeneration costs may limit its application, particularly for small- and medium-scale industries in developing countries. Rice husks therefore represent a cost-effective alternative where moderate treatment efficiency can achieve compliance with wastewater discharge standards at substantially lower operating costs (Demirbas, 2008; Crini & Lichtfouse, 2019).

For successful industrial implementation in Tanzania, adsorption using rice husks should be integrated with existing wastewater treatment processes rather than considered a standalone treatment technology. Preliminary treatment steps such as sedimentation, oil separation, and pH adjustment would improve adsorption performance by reducing competing contaminants. Pilot-scale studies under continuous-flow conditions are recommended to evaluate long-term adsorption performance, regeneration efficiency, operational costs, and compliance with national industrial effluent discharge standards before full-scale commercialization (United Republic of Tanzania, 2021; Fu & Wang, 2011).

CONCLUSION AND RECOMMENDATION

This study investigated the adsorption potential of rice husks for the removal of lead (Pb^{2+}) and zinc (Zn^{2+}) from contaminated water. The physicochemical characterization showed that rice husks possessed favourable properties for adsorption, including a near-neutral pH of 6.16, ash content of 15.20%, and fibre content of 83%. These characteristics indicate the presence of functional groups and mineral components that support heavy metal removal through adsorption mechanisms such as surface complexation, ion exchange, and electrostatic interactions. The adsorption experiments showed that the highest removal efficiencies within the investigated experimental conditions were obtained at pH 6.4, particle size of 0.8 mm, and adsorbent dosage of 10 g. However, statistical analysis revealed that changes in pH, particle size, and adsorbent dosage did not produce significant differences in lead and zinc removal efficiencies. Therefore, these conditions should be interpreted as the experimentally observed favorable conditions rather than statistically confirmed optimum conditions. The absence of significant differences suggests that rice husks exhibited relatively consistent adsorption performance across the tested operational ranges, providing flexibility in selecting operating conditions based on economic and practical considerations.

Generally, the findings demonstrate that rice husks have potential as a low-cost and environmentally sustainable adsorbent for removing lead and zinc from contaminated water. Their availability as an agricultural residue makes them particularly attractive for wastewater treatment applications in developing regions. However, future studies should incorporate kinetic models (e.g., pseudo-first-order and pseudo-second-order models), isotherm models (e.g., Langmuir and Freundlich models), and characterization techniques such as Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray (EDX) analysis to further elucidate the adsorption mechanism and optimize the application of rice husks for heavy metal removal.

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