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DEVELOPMENT OF A LOW COST SYSTEM FOR THE REMOVAL OF HEAVY METALS FROM POLLUTED WATER

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ABSTRACT: *Water pollution by heavy metals has become one of the most harmful environmental issues. This study developed a low cost heavy metal (lead and chromium) removal system from polluted water using locally available adsorbents, such as sawdust, pawpaw (Carica papaya) seeds and sand. Heavy metals constitute a serious threat to human health and the entire biological system due to their toxic, mutagenic, and carcinogenic nature even at trace concentrations. The objective of this study was to design and construct a low cost heavy metals removal system, test its performance and do a cost analysis of the system. In this process, a filter column made of a plastic container of height 54 cm and diameter 20.4 cm was constructed. Characteristic properties of the adsorbents were obtained from secondary sources and were found to possess functional groups (hydroxyl, carbonyl, aldehyde and amine) capable of binding to metal ions. Optimization was done with a sawdust and pawpaw seeds/sand height ratios of 10:10, 10:15, 15:10, 20:10 and 10:20 cm respectively in the filter column. Results showed that the best removal efficiencies were 99.88% for lead and 85.57% for chromium with a sawdust to pawpaw seeds/sand mixture ratio of 10:20 cm. Statistical analysis showed a significant difference ($p < 0.05$) in the final concentrations of lead and chromium using the various adsorbent proportions. Cost per liter of treated water was deduced to be 15.5 FCFA. This cost can be afforded by many households with low incomes and thus, this low cost heavy metals removal technology is highly recommended.*

KEYWORDS: Polluted water, Sawdust, Pawpaw seeds, Sand, Heavy metals.

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INTRODUCTION

Water shortage is a critical global issue, exacerbated by factors such as climate change, industrialization, and urbanization. As the world's population faces increasing water stress, the availability of clean drinking water is becoming limited (Oki, 2006). The discharge of pollutants, particularly heavy metals, from industrial activities into aquatic environments further compounds the problem. Metallic water pollution is becoming one of the most harmful ecological issues requiring a great part of scientific interest. It constitutes a serious threat to human health and the entire biological system due to their toxic, mutagenic, and carcinogenic nature even at trace concentrations (Wijayawardena *et al*., 2016). Polluting metals are introduced into the environment through diverse anthropogenic activities, including metallurgical industry, electroplating, leather tanning, electronic and pigment manufacturing (Tchounwou *et al.*, 2012; Abu-El-Halawa & Zabin, 2017). These contaminants are characterized by their persistent resistance to chemical or biological decomposition and their high environmental mobility. Furthermore, they exhibit an extreme bioaccumulation tendency in the food chain hence exposing human health to slow poisoning (Kumar *et al.*, 2017). Therefore, there is the need for a low cost heavy metals removal system in polluted water.

Studies have reported contamination of drinking water with heavy metals such as arsenic, cadmium, manganese, mercury, and lead in various regions and countries around the world, posing serious health risks to the population. Conventional technologies such as ion exchange, chemical precipitation, reverse osmosis, and membrane separation have been employed to remediate toxic metals pollution (Mathew *et al.*, 2014). However, these conventional technologies require a high level of expertise and high capital and operational cost (Abas *et al*., 2013). Although adsorption techniques are relatively cheap, there is a pressing need to replace commercial adsorbents like activated carbon, zeolite, activated alumina and silica gel with the low cost adsorbents. The method of adsorption using commercially activated carbon is costly, especially for developing countries.

Removing heavy metals from polluted water is essential to preserve clean water resources and safeguard human well-being. This study focuses on the removal of lead and chromium, two toxic heavy metals, from polluted water using low-cost adsorbents (sawdust and pawpaw seeds). The main objective of this study was to design and construct a cost-effective heavy metals removal system using low-cost adsorbents for the treatment of polluted water. The specific objectives were to design and construct a heavy metals removal system, assess the performance of the system in removing heavy metals and determine the cost per liter of treated water.

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MATERIALS AND METHODS

Material Selection

The selection of materials for the heavy metals removal system was based on several criteria, including their quantitative availability, economic considerations, suitability for optimal performance based on research, and viability in service.

Design Process

The heavy metals removal system was designed to consist of a filter column, a layer of sawdust, and a layer composed of a mixture of powdered pawpaw seeds and sand. A hand-drawn sketch of the system was initially made and later refined using computer-aided design (CAD) software, SketchUp Pro 2021. Figure 1 shows an illustration of the computer aided design of the system.

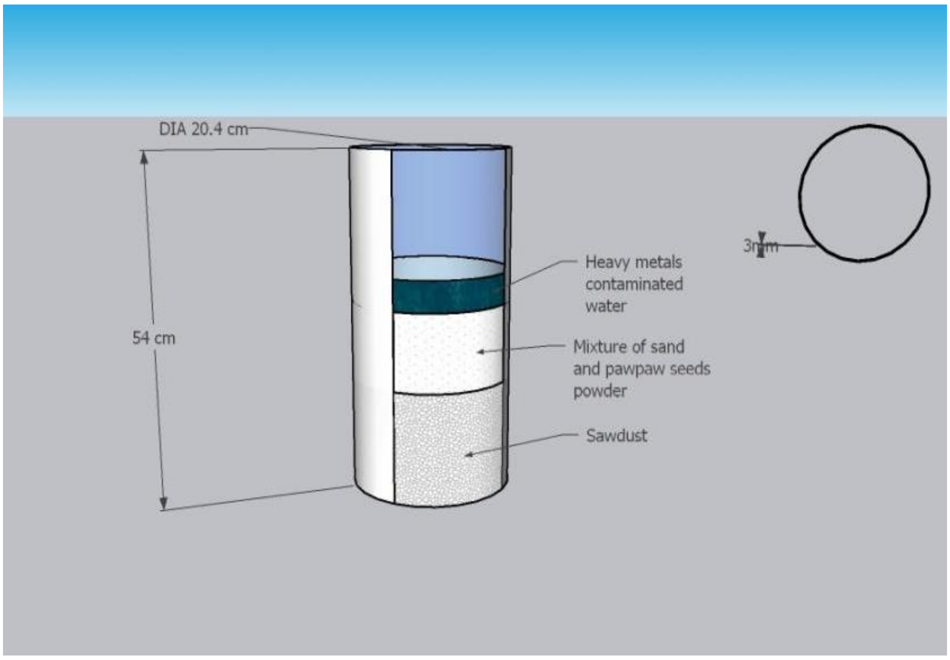

Figure 1: Design of the system

Construction Process

The construction process involved joining and sealing two plastic buckets to create the filter column. Plastic was chosen for its corrosion resistance and easy availability. Sawdust and pawpaw seeds were prepared and used as low-cost adsorbents. Sawdust of size range 0.3 - 0.5 mm was washed, sieved, and oven dried overnight at 30 ℃ to reduce moisture content. Pawpaw seeds were washed, sun-dried then oven dried overnight at 70 ℃ to reduce its moisture content and activate its adsorption properties. It was then crushed, and ground to form a fine powder of 65 micrometers particle size. According to Shooto and Eliazer (2019), the seeds from ripe pawpaw have a better adsorption capacity than those of unripe pawpaw fruits, hence seeds from ripe pawpaw fruits were selected for this study. Sand of particle sizes ranging from 0.05 - 0.4

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mm was also washed, dried and then mixed with the pawpaw seeds powder at a ratio 1:1 to create a layer of the filter media.

Performance Test

The performance test was carried out at the Research Unit of Soil Analysis and Environmental Chemistry, University of Dschang, Dschang, Cameroon. The removal efficiency or retention rate of the media was carried out by varying the proportions of sawdust and powdered pawpaw seeds/sand mixture and running polluted water (prepared solutions of lead and chromium of initial concentrations of 100 ppm) through the system. Distilled water was used in preparing the contaminated water samples because ordinary water could contain the heavy metals being tested for and hence could give inaccurate results. Proportions of the sawdust to pawpaw seeds/sand mixture were 10:10, 10:15, 15:10, 10:20 and 20:10 cm respectively with a constant flow rate of 1.3 L/hr. The proportions used in this study was adopted from a study carried out by Akiladevi et al. (2017) who worked on the removal of iron from synthetic wastewater using sawdust and rice husk. For each proportion, samples were sent through the column twice to check for precision. A porous cloth was placed at the mouth of the tap from inside to prevent passage of sand or sawdust which could block the outflow of the treated water.

A 30 L drum with a valve incorporated into it was used to control the flow rate of the contaminated water running through the filter column, hence maintaining a constant flow. The efficiency of the system was tested using the formula proposed by Ong *et al.* (2011) as presented in equation 1.

$$RE = \frac{(C_o - C_1)}{C_o} \, x \; 100 \qquad (1)$$

Where

RE = removal efficiency,

C_o = Initial metal concentration

C_1= Final metal concentration

Lead and chromium concentrations in the aliquot were analyzed using a UV vis spectrophotometer at a wavelength of 440 nm.

Data Analysis

The means of the different sample results were analyzed through the t-test and the analysis of variance (ANOVA) using R (3.6.3 version) statistical software. The paired t-test, single and two-factor ANOVA were used to determine the possibility of a significant difference in mean values. The overall analysis was done at a 95% significance level and results presented in bar charts.

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Cost Analysis of the System

This system is meant to be applied in households which do not have enough capital to install the more conventional methods used in the removal of heavy metals from water. Hence the cost analysis to find out the cost per liter of the treated water by the system was an important factor in this research. To calculate the cost per liter of water for the low cost system, the depreciation straight-line method was applied. To do this, the total cost of the system over its useful life, including the initial cost and the depreciation cost was considered.

The first step was to determine the initial cost of the system. This includes the cost of purchasing the equipment, installation, and any other expenses associated with setting up the system.

Initial cost (in FCFA) = Sum of all construction materials (2)

The cost of the heavy metals removal system was done by summing the price of each material used in the construction as shown in Table 1.

Table 1: Cost of the heavy metals removal system (Fixed cost)

Item	**Quantity**	**Unit Cost (FCFA)**	**Total Cost (FCFA)**
Sawdust	20 kg	75	1500
Pawpaw seeds	10 kg	5000	50000
Troughs	2	5000	10000
Valve	1	1500	1500
Sand	20 kg	50	1000
Patching of troughs	1	2000	2000
Grand Total			**66000**

The next step was to determine the useful life of the system. This would be the estimated period over which the system is expected to be in use and effective in removing lead and chromium from water. Assuming that the components used in constructing the filter column are durable and can last for about over a decade, the useful life of this system depends solely on the media components, sawdust, pawpaw seeds and sand. According to Rahmawati et al. (2016), 100 mg of pawpaw seeds can remove heavy metals in 20 mL of contaminated water for 1 hour before attaining equilibrium. Akiladevi *et al.* (2017) also observed that 0.5 g of sawdust can remove heavy metals in 100 mL of water for 1 hour. Hence, the quantity of media purchased (50 kg) was estimated to take 5 months (150 days) to reach equilibrium and stop removing heavy metals.

Salvage value is the estimated residual value of an asset at the end of its useful life, or the amount that an asset can be sold for after it has reached the end of its useful life. For this system, the salvage value was assumed to be zero.

The 10% maintenance rule is a rule of thumb that is commonly used to estimate the annual maintenance cost of a capital asset, such as a piece of equipment. According to this rule, the

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annual maintenance cost of an asset is likely to be approximately 10% of the asset's initial cost. Hence, the 10% maintenance rule was assumed for this system of the initial cost.

Maintenance cost = 0.1 x initial cost (Assuming 10% of initial cost for maintenance) (3)

Maintenance cost = 0.1 x 66000 = 6600 FCFA (4)

The operating cost was calculated as follows

$$\text{Operating Cost (in FCFA)} = \frac{\text{Initial cost} + \text{Maintenance cost}}{Useful\ life}$$

(5)

$$\text{Operating Cost (in FCFA)} = \frac{(66000 + 6600)\text{FCFA}}{150\ days} = 484\ FCFA/day$$

(6)

The total amount of water produced per day was the next step assuming the system is used daily. The system produces 1.3 L of water per hour. This implies it produces 31.2 L/day.

Finally, the cost per liter of water is calculated as follows:

$$\text{Cost per liter of treated water (FCFA/L)} = \frac{Operating\ cost}{Liters\ of\ water\ produced\ per\ day}$$

(7)

$$\text{Cost per liter of treated water (FCFA/L)} = \frac{484\ FCFA}{31.2\ L} = 15.5\ \text{FCFA}$$

(8)

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RESULTS AND DISCUSSIONS

Performance Test Results

Figure 6 shows the optimization results for Pb removal. The lowest final concentration of Pb was 0.1165 pmm for sawdust to pawpaw seeds/sand ratio of 10:20 cm (1:2), while the highest final concentration of Pb was 0.1535 ppm for sawdust to pawpaw seeds/sand ratio of 10:10 cm (1:1), giving rise to removal efficiencies of 99.88% and 99.85% respectively. Statistical analysis confirmed a significant difference in the final concentrations ($p < 0.05$), with pawpaw seeds proving more effective than sawdust in Pb removal.

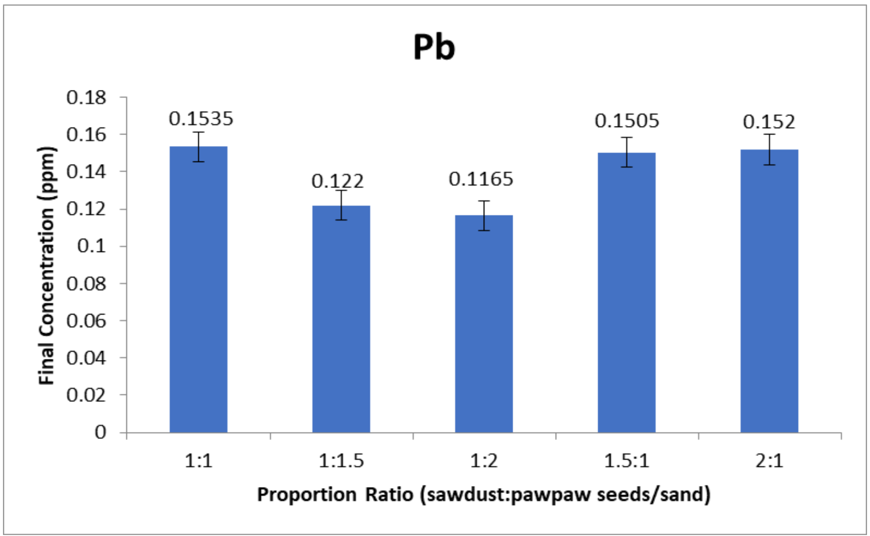

Figure 6: Results of optimization of different media components for Pb

Figure 7 shows the optimization results for Cr. The sawdust to pawpaw seeds/sand ratio of 10:20 cm (1:2) gave the lowest final concentration of 14.433 ppm, accounting to Cr removal efficiency of 85.57%. Statistical analysis confirmed a significant difference in the final concentrations ($P<0.05$), again demonstrating the superiority of pawpaw seeds over sawdust in Cr removal.

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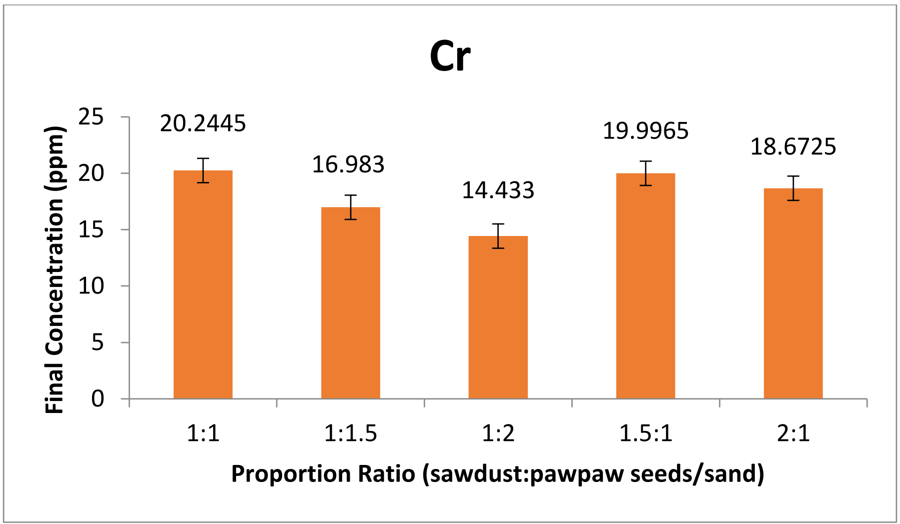

Figure 7: Results from the optimization of different media components for Cr

3.2 Comparison of removal efficiencies for Pb and Cr:

A comparative analysis of the results revealed a significant difference in the final concentrations of both heavy metals (P<0.05). The 1:2 ratio was found to be the most efficient for both Pb (removal efficiency of 99.88 %) and Cr (removal efficiency of 85.57 %).

Figure 8 presents the removal efficiencies of various proportion ratios for Pb and Cr.

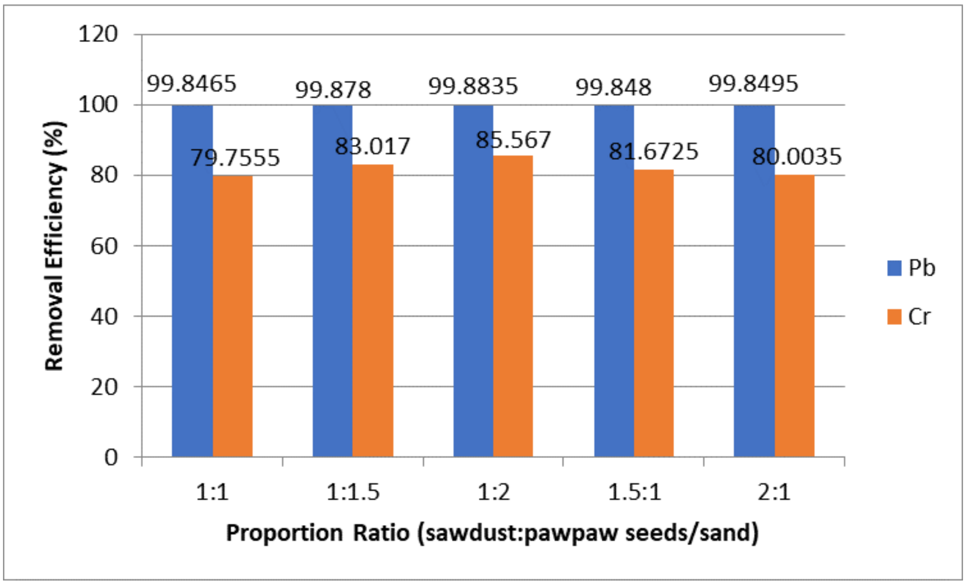

Figure 8: Illustration of removal efficiencies of various proportion ratios for Pb and Cr

This study demonstrated the effectiveness of the low-cost system for the removal of Pb and Cr from contaminated water. The 1:2 ratio of sawdust to pawpaw seeds/sand was found to be the most efficient in both cases. The low-cost heavy metal removal system exhibited removal efficiencies above 50% for both Pb and Cr. The system's efficiency was higher for Pb removal compared to Cr, potentially due to the adsorbent's affinity for Pb. The method of removal and

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media thickness were identified as factors influencing the removal rate of Pb and Cr. Additionally, the method of removal might also play a role, suggesting that alternative methods, such as agitation, could potentially increase the removal efficiency for Cr. Increasing the thickness of the media layer could also enhance the removal rate of Cr. The results highlighted the importance of media proportion ratio and thickness in optimizing the heavy metals removal process. While the system exhibited favorable removal efficiencies, adsorption took place due to the strong electrostatic attraction between the functional groups found in the adsorbents and the Pb and Cr. Electrostatic interaction occurred between the positively charged heavy metals and negatively charged carbon adsorbents, especially with the presence of functional groups (Wang *et al.*, 2017). The removal efficiencies could also be due to complexation, where surface complexation (inner- and outer-sphere) forms multi atom structures (complexes) with unique metal-functional groups interactions (Fu & Wang, 2011), playing a predominant role in adsorption of heavy metals onto carbon adsorbents (Wang *et al.*, 2017). Overall, these findings highlight the importance of optimizing both adsorbent properties and operational parameters to achieve higher removal efficiencies for different heavy metals in the system.

Cost Analysis Results

From the calculations, it was observed that cost per liter of the treated water is 15.5 FCFA. Previous works on other heavy metal removal techniques showed that reverse osmosis is 0.86 $/L which is about 523 FCFA (Atikol *et al.*, 2005), chemical precipitation is 4.52 €/m^3 which is about 2965 FCFA (Oncel *et al.,* 2013), and coagulation is 1.98 €/m^3 which is about 1296 FCFA. This shows that the proposed system is relatively cheap as compared to other conventional methods of removal of heavy metals from polluted water.

CONCLUSION

This study successfully developed a low-cost heavy metals removal system using a combination of sawdust and pawpaw seeds/sand mixture as adsorbents. The system demonstrated high removal efficiencies for lead (99.88%) and chromium (85.57%) when using a sawdust to pawpaw seeds/sand proportion ratio of 1:2. Cost analysis revealed that the system is economically viable given that its cost per liter of treated water was 15.5 FCFA, making it a promising alternative to conventional heavy metals removal methods. The study identified layer thickness and proportion ratio as critical factors influencing removal efficiency. The system could be integrated into wastewater treatment plants, particularly in developing and less developed countries

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CONFLICT OF INTEREST

The authors declare that there are no competing interests concerning the publication of this article.

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