Research Output Journal of Biological and Applied Science 5(3):1-11, 2025

ROJBAS Publications ONLINE ISSN: 1115-9200

https://rojournals.org/roj-biological-and-applied-science/ PRINT ISSN: 1115-6120

https://doi.org/10.59298/ROJBAS/2025/53111000

Assessment of Levels of Selected Heavy Metals and Their Removal in Water Using Biochar Adsorption along Ggaba Market

Lasuba Joseph Chaplain, and Ampaire Wycliffe

School of Natural and Applied Sciences Kampala International University, Kampala, Uganda

ABSTRACT

Water contamination by heavy metals is a growing environmental concern, particularly in urban markets such as Ggaba Market in Uganda, where human activities contribute to pollution. This study aims to assess the concentration of selected heavy metals; lead (Pb), iron (Fe), nickel (Ni), cadmium (Cd), and mercury (Hg) in water from Ggaba Market and evaluate the effectiveness of bone char as an adsorbent for their removal. Water samples were collected from two different locations, analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), and subjected to biochar treatment. The results indicated high concentrations of heavy metals in untreated water samples, with iron, lead, and cadmium exceeding World Health Organization (WHO) safety limits. Biochar treatment significantly reduced the levels of heaviest metals, particularly lead, iron, and cadmium, achieving near-complete removal. However, nickel and mercury were less effectively removed, indicating the need for optimization or complementary treatment methods. These findings highlight the severity of heavy metal contamination in Ggaba Market and underscore the potential of biochar as a cost-effective and eco-friendly water purification technique. The study recommends the adoption of biochar in water treatment systems, further research into its optimization for mercury and nickel removal, and increased public awareness of water pollution risks.

Keywords: Heavy metals, Biochar treatment, Environmental pollution, Water pollution, Public health, Water quality

INTRODUCTION

Uganda, located in East Africa, is a landlocked country bordered by Kenya to the east, South Sudan to the north, the Democratic Republic of the Congo to the west, and Rwanda and Tanzania to the south. Known as the "Pearl of Africa," Uganda is celebrated for its diverse landscapes, which include lush forests, rolling hills, and the majestic Lake Victoria, one of the largest lakes in the world [1]. Despite its natural beauty and resources, Uganda faces challenges such as poverty, political instability, and health issues, including those related to water quality and sanitation [2]. Efforts to improve infrastructure and public health are ongoing, with a focus on sustainable development and environmental conservation.

Uganda faces significant water quality challenges, particularly in urban areas like Ggaba Market, which are characterized by pollution from water sources, inadequate infrastructure, and high population density [3]. Contamination of water sources, such as lakes and rivers, poses health risks to residents who rely on these sources for drinking and domestic use. Poor infrastructure for water treatment and distribution exacerbates these issues, as many urban areas lack reliable systems for sewage management and wastewater treatment [4].

Research has shown elevated levels of heavy metals in water sources across Uganda, such as lead, cadmium, and mercury in Lake Victoria waters. Groundwater sources in some regions contain heavy metals, often exceeding permissible limits, linked to mining activities and improper disposal of hazardous waste [2].

Several factors contribute to water pollution in urban areas like Ggaba Market, including industrial discharge, urban runoff, inadequate waste management, agricultural practices, and population growth [5]. Factories and industries often release untreated wastewater containing heavy metals and other pollutants into nearby water bodies, directly impacting water quality. Poor solid waste management practices lead to the accumulation of waste in water bodies,

introducing contaminants and affecting water quality [6]. Rapid urbanization and population growth further stress existing water resources, exacerbating pollution issues.

Water pollution is a critical environmental issue that poses significant risks to public health and ecosystems worldwide. Among the various contaminants, heavy metals have emerged as a major concern due to their toxic effects and persistence in the environment [7]. Sources of heavy metal contamination often include industrial discharges, agricultural runoff, and urban waste, making densely populated areas, such as Ggaba Market, particularly vulnerable [8]. Ggaba Market, located near the shores of Lake Victoria in Uganda, serves as a bustling hub for trade and commerce. However, its proximity to both industrial activities and informal waste disposal sites raises concerns about the quality of water used by vendors and consumers alike [9]. Heavy metals such as lead, cadmium, and mercury are frequently found in these water sources, posing threats to human health through direct consumption and indirect exposure via contaminated food [10].

To address this pressing issue, effective water treatment methods are essential. Adsorption has gained attention as a promising technique for removing heavy metals from water due to its cost-effectiveness and efficiency [11]. Various materials, including activated carbon, agricultural by-products, and natural clays, have been explored as potential adsorbents. Understanding the levels of heavy metals present in Ggaba Market's water and evaluating the removal efficiency of these adsorbents is crucial for developing effective water purification strategies. This study aims to assess the concentration levels of selected heavy metals in the water around Ggaba Market and to investigate the effectiveness of different adsorption materials in reducing these contaminants [12]. By identifying optimal conditions for metal removal, this research seeks to contribute to improved water quality and public health outcomes in the region.

The increasing presence of heavy metals in water sources poses a significant threat to public health, particularly in densely populated areas like Ggaba Market, Uganda. Preliminary observations suggest that water samples from this region may contain high concentrations of harmful metals such as lead, cadmium, and mercury, which can adversely affect the health of local communities relying on these sources for drinking and food preparation. Despite the potential of adsorption as a viable method for removing these contaminants, there is limited research on the effectiveness of various adsorbent materials in this specific context. Additionally, the local population may lack awareness of the risks associated with heavy metal exposure and the importance of effective water treatment solutions. This research aims to assess the levels of selected heavy metals in the water around Ggaba Market and evaluate the efficiency of different adsorption materials in mitigating this pollution. The findings provide critical insights into improving water quality and protecting public health in the region.

The study on heavy metal levels in Ggaba Market water is crucial for public health, environmental management, and community awareness. It aims to identify harmful metal concentrations, providing information to mitigate health risks, especially for vulnerable populations. The findings will raise community awareness about water quality issues, encouraging better management practices. The research will also evaluate the effectiveness of bone char as an adsorbent for heavy metals, leading to the development of affordable water treatment solutions. The data will also guide policymakers in formulating regulations and interventions to reduce heavy metal pollution in Ggaba Market.

METHODOLOGY

Ggaba Market, situated on the shores of Lake Victoria in Kampala, Uganda, is a vital hub for fish trading, domestic water abstraction, and recreational activities. However, it also faces significant anthropogenic pressures from commercial, residential, and industrial activities. The lake's water quality is influenced by seasonal rainfall, inflow from local streams, and urban effluent discharge. The lake's water has a pH range of 6.5 to 7.5, with eutrophication and stratification causing fluctuations. It also contains trace metals like lead, cadmium, and mercury. Pollution sources include domestic wastewater, industrial runoff, oil-related activities, and market activities. The sediment composition is predominantly sandy clay and silty clay, with organic-rich layers due to market activities. The geological characteristics include elevated organic matter, iron and manganese oxides acting as sinks for heavy metals, and potential accumulation of hydrocarbons from oil residues linked to fishing and transport activities. Sediment-water interaction influences sediment resuspension and can release bound metals, posing ecological and environmental concerns.

2.1. Description of the water bodies and sediment characteristics in Ggaba market

Ggaba Market, located in Kampala, Uganda, is a significant water body along the northern shores of Lake Victoria, Africa's largest freshwater lake. The lake's water quality is influenced by seasonal rainfall, urban runoff, and inflows from streams like the Nakivubo Channel. Key contaminants include elevated nitrogen and phosphorus from wastewater discharge, heavy metals like lead, cadmium, mercury, and nickel, and hydrocarbons from oil residues from boat maintenance and fuel handling. Primary pollution sources include domestic wastewater discharge, market

runoff, boat and fishing activities, and industrial effluents from Kampala's urban areas. Sediment dynamics include erosion and deposition, as well as resuspension due to wind-driven waves and human activities.

2.2 Equipment, Materials, Reagents, Chemicals and Standards

2.2.1 Equipment and Materials

The following are some of the equipment and materials that were used in the water, sediments sampling and analysis; Water Sampling Bottles, Sampling Pumps, Sampling Rods, Inductively Coupled Plasma Mass Spectrometer (ICP-MS) Centrifuge. Water Sampling Containers, Preservatives, pH Buffers, Standard Solutions, Filter Papers, Membrane Filters, Sampling Tubes, Gloves, Lab Coats, Data Loggers

2.2.2. Reagents, chemicals, and chemical standards

The reagents and chemicals that were used include Nitric acid (HNO_3), Hydrochloric acid (HCl), Sulfuric acid (H_2SO_4), Hydrogen peroxide (H_2O_2), Ammonium hydroxide (NH4OH), Sodium hydroxide (NaOH), Potassium dichromate ($K2Cr_2O_7$), Methyl isobutyl ketone (MIBK). Chemical Standards like Lead (Pb) standard solution, Mercury (Hg) standard solution, Cadmium (Cd) standard solution, Chromium (Cr) standard solution used for calibration of analytical instruments, such as AAS, Multi-element standard solution, Certified reference materials (CRMs), Quality control (QC) standards.

2.3 Sample collection, preservation, and transport

2.3.1 Sample collection

Duplicates of water samples were taken from two point from the selected different sampling locations along the 1 km stretch along Ggaba market. A total of 6 samples were collected 100 meters around sample site A and B named Point A1 and point B1 respectively.

2.3.2 Water sampling

The sampling of water from the different sites was performed according to Method ID: LSASDPROC-201-R6; US.EPA (2023) which specifies the procedure for the sampling of water. Also, guidance from ISO 5667-3- Water quality sampling, preservation, and handling of water samples was considered. Each water sample was collected in a 500 ml acetone-rinsed dark glass bottle with a PTFE cap liner and labelled accordingly for easy identification and traceability.

The labelled bottles containing the water samples were placed and stored in a cool box with Ice blocks for chilling them and transported to the laboratory for analysis. After reception in the laboratory, the samples were halved into duplicate samples. The six (6) duplicate samples were treated with biochar and all the 12 samples were immediately transferred into the fridge and stored at 2-8°C. Analysis of the samples commenced after 24 hours for all treated and untreated samples.

2.4 Sample preparation and extraction

2.4.1 Bone char preparation from Cow bones

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Sample cow bone *Biochar*

The sample cow bone was thoroughly cleaned to remove any debris, oils, and other contaminants and later dried. The bone was crushed into smaller pieces to allow for faster carbonization. The bones were heated in air free environment in ideal temperature for pyrolysis of 600°C and maintained for 3 hours. During this time, the bones underwent pyrolysis, breaking down into biochar (carbonized bones) and releasing gases. The process was closely monitored to ensure the system remained sealed, and the gases are directed appropriately.

When the pyrolysis process was complete, the carbonized bones were removed and cooled. After cooling, the biochar was crushed and sieved to achieve uniform particle sizes. The biochar was then stored in an airtight container to prevent moisture absorption, keeping it dry and away from direct sunlight.

2.4.2 Water samples

For heavy metals, the samples were prepared and extracted as per American Public Health Association (APHA) Standard Methods for the Examination of Water and Waste Water, 24th Edition (2023). The samples were filtered using a whatmann qualitative filter paper into 15ml falcon tubes for ICP-MS analysis. This was done to ensures that the sample is free from any particulate matter.

The samples were then transferred to ICP-MS for analysis of the heavy metals using ICP-MS (model; thermos-scientific ICAP RQ 03358). The standards were prepared by diluting the stock standard solution to different concentrations covering the concentration range of the analytes in the samples. High quality deionized water (ultra-pure ICPMS) and nitric acid (ultra-pure grade) was used for accurate results. ICP-MS tuning solutions (A and B) were used to optimize the performance of the instrument in order to achieve accurate and precise results in element analysis.

This involved selecting the instrument modes (KED and STD) and selecting the element in the software (QTEGRA). The instrument was allowed to warm the plasma for 20 minutes prior to calibration and sample analysis. It also involved instrumental parameter setting for plasma power, nebulizer gas flow rate, lens voltage and mass spectrometer setting for maximum sensitivity and stability.

Table 1: Showing parameter setting for ICP-MS

Parameter	Specification
Forward power	1500W
Nebulizer gas	0.9L/min
Auxiliary gas	0.8L/min
Cool gas flow	14.0L/min
Sample uptake/ wash time	45 sec each
CRC conditions	45 ml/min at He, 3V KED
Total acquisition time	5 minutes.

Source: Primary Data,2024

Quality control and assurance

Quality control samples included blanks, triplicates and spikes QC sample which were prepared alongside the samples to assess the accuracy, precision and recovery of the analysis. Before sample analysis, the instrument was first calibrated using the prepared standards.

Calibration

The calibration curves were constructed by plotting the instrument response (counts) against the known concentrations of the standard solutions. A multi-point calibration curve was employed to ensure accurate quantification across the analytical range.

Data analysis

The instrument measured the intensity of the ions generated by the analytes in the plasma and quantifies their concentrations based on the calibration curve. The raw data obtained from the instrument was processed using specialized software (QTEGRA) to calculate the concentrations of the analytes in the samples. Corrections for background noise, interference and matrix effects were applied during data analysis.

RESULTS

Calibration results

Table 2: Showing the data obtained from the procedure Blank

Category	57Fe (KED)	60Ni (KED)	111Cd (KED)	202Hg (STD)	208Pb(KED)
Concentration average 1	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L
Concentration per Run 1	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L
Concentration per Run 2	5.8 %	10.3 %	32.0 %	8.1 %	1.6 %
Concentration per Run 3	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L
Concentration RSD 1 $[RSD = \left(\frac{S}{X}\right) * 100\%]$	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L	0.000 µg/L

Table 3: Calibration data at 100 µg/L concentration

Category	Concentration average 1	Concentration RSD 1	Standard Concentration 1
57Fe (KED)	138.342 µg/L	3.3 %	100.000 µg/L
57Fe (STD)	139.818 µg/L	2.9 %	100.000 µg/L
60Ni (KED)	130.725 µg/L	2.8 %	100.000 µg/L
60Ni (STD)	129.132 µg/L	5.1 %	100.000 µg/L
111Cd (KED)	115.247 µg/L	4.6 %	100.000 µg/L
111Cd (STD)	114.646 µg/L	5.0 %	100.000 µg/L
202Hg (KED)	109.746 µg/L	3.0 %	100.000 µg/L
202Hg (STD)	112.783 µg/L	1.5 %	100.000 µg/L
208Pb (KED)	122.759 µg/L	26.2 %	100.000 µg/L
208Pb (STD)	104.649 µg/L	2.0 %	100.000 µg/L

Calibration curve

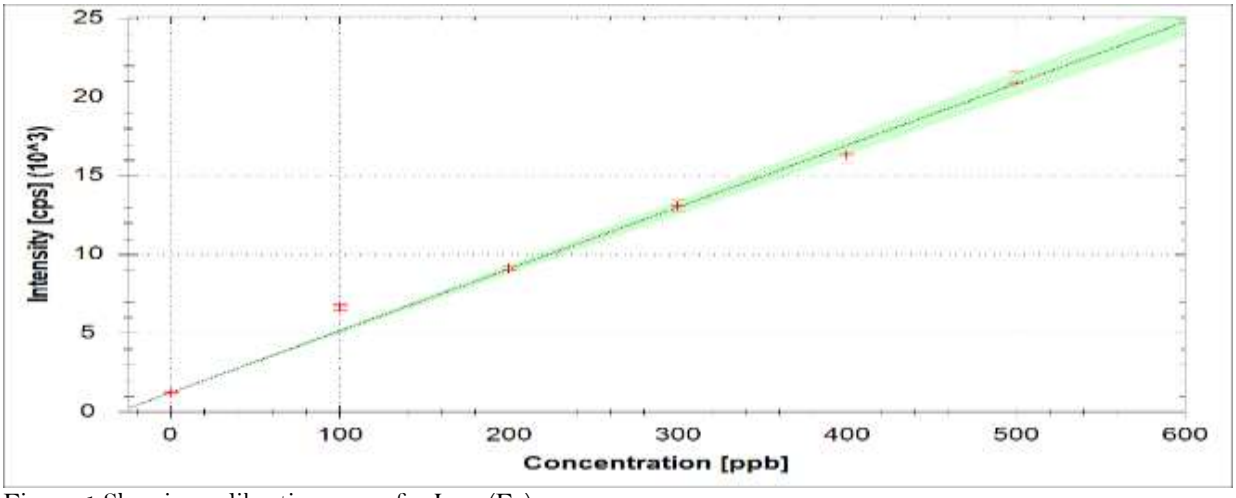

Figure 1 Showing calibration curve for Iron (Fe)

Sample results

Table 4: Average concentration of selected heavy metals in water sample A1

Category	57Fe (KED)	60Ni (KED)	111Cd (KED)	202Hg (STD)	208Pb(KED)
Concentration average 1	180.136 µg/L	19.546 µg/L	18.451 µg/L	0.941 µg/L	30.326 µg/L
Concentration per Run 1	186.083 µg/L	20.502 µg/L	18.419 µg/L	0.979 µg/L	30.640 µg/L
Concentration per Run 2	178.947 µg/L	19.515 µg/L	18.748 µg/L	0.967 µg/L	29.769 µg/L
Concentration per Run 3	175.378 µg/L	18.620 µg/L	18.187 µg/L	0.877 µg/L	30.569 µg/L
Concentration RSD 1 $\left[\boldsymbol{RSD} = \left(\frac{S}{X}\right) * \mathbf{100\%}\right]$	3.0 %	4.8 %	1.5 %	5.9 %	1.6 %

Table 5: Average concentration of selected heavey metals in water sample A2 (Duplicate Sample A1 subjected to Biochar)

Category	57Fe (KED)	60Ni (KED)	111Cd (KED)	202Hg (STD)	208Pb(KED)
Concentration average 1	ND	ND	ND	0.697 µg/L	ND
Concentration per Run 1	ND	ND	ND	0.688 µg/L	ND
Concentration per Run 2	ND	ND	ND	0.735 µg/L	ND
Concentration per Run 3	ND	ND	ND	0.668 µg/L	ND
Concentration RSD 1 $\left[\boldsymbol{RSD} = \left(\frac{S}{X}\right) * \mathbf{100\%}\right]$	11.3 %	37.8 %	2.6 %	4.9 %	1.9 %

Table 6: Average concentration of selected heavey metals in water sample B1

Category	57Fe (KED)	60Ni (KED)	111Cd (KED)	202Hg (STD)	208Pb(KED)
Concentration average 1	15.878 µg/L	2.439 µg/L	0.019 µg/L	0.688 µg/L	ND
Concentration per Run 1	20.208 µg/L	2.292 µg/L	0.017 µg/L	0.700 µg/L	ND
Concentration per Run 2	9.510 µg/L	2.421 µg/L	0.011 µg/L	0.645 µg/L	ND
Concentration per Run 3	17.916 µg/L	2.603 µg/L	0.030 µg/L	0.720 µg/L	ND
Concentration RSD 1 $\left[\boldsymbol{RSD} = \left(\frac{S}{X}\right) * \mathbf{100\%}\right]$	35.5 %	6.4 %	50.9 %	5.7 %	1.0 %

Table 7: Average concentration of selected heavey metals in water sample B2 (Duplicate Sample B1 subjected to Biochar)

Category	57Fe (KED)	60Ni (KED)	111Cd (KED)	202Hg (STD)	208Pb(KED)
Concentration average 1	ND	0.363 µg/L	ND	0.565 µg/L	ND
Concentration per Run 1	ND	0.307 µg/L	ND	0.521 µg/L	ND
Concentration per Run 2	ND	0.398 µg/L	ND	0.638 µg/L	ND
Concentration per Run 3	ND	0.385 µg/L	ND	0.537 µg/L	ND
Concentration RSD 1 $[RSD = \left(\frac{S}{X}\right) * 100\%]$	13.5 %	13.5 %	21.0 %	11.2 %	2.5 %

Table 8: World Health Organisation maximum axceptable limits it portable water

Metal	WHO Guideline value (µg/L)
Lead (Pb)	10
Cadmium (Cd)	3
Mercury (Hg)	1
Nickel (Ni)	20
Iron (Fe)	300

DISCUSSION

From table 2, the blank samples showed zero concentration in all runs, indicating no contamination or background interference. However, in Run 2, the samples showed high variation, indicating potential contamination or instrumental fluctuations. The relative standard deviation (RSD) was zero, except in Run 2, indicating the calibration's reliability. The zero concentration in other two runs validate the instrument's precision and confirms heavy metal contamination is unlikely. The elevated values in Run 2 warrant further investigation, possibly due to instrument drift, contamination during sample handling, or software calibration inconsistencies. Despite this anomaly, the overall blank test indicates a low detection limit, confirming the instrument's ability to differentiate between actual analytes and background noise.

From the table 3 (calibration data), the concentrations of Fe, Ni, Cd, and Pb are slightly higher than the standard 100 µg/L, possibly due to instrument sensitivity, matrix effects, or calibration errors. The Relative Standard Deviation (RSD) values are mostly below 5%, indicating good precision in repeated measurements. However, Pb (KED) exhibits an RSD of 26.2%, indicating variability in lead measurements and potential instability in its detection. Most metals have good agreement between the KED and STD modes, with minimal difference between KED and STD values, indicating reliable instrument calibration. The calibration curve was a linear function, ensuring the instrument response was proportional to analyte concentration. Pb showed the highest deviation and variation (26.2% RSD), which may require additional recalibration or method optimization. Lead contamination in water and sediments is a major environmental issue, especially in industrial and oil exploration areas like the Albertine Graben. It can enter aquatic ecosystems through industrial discharges, atmospheric deposition, and leaching from poorly managed landfills [13]. Lead bioaccumulates in aquatic organisms, affecting fish and higher food chain levels. The World Health Organization recommends a limit of ≤0.01 mg/L for drinking water [14]. Monitoring and mitigation include regular monitoring, stringent waste management practices, and remediation methods like dredging, capping, and phytoremediation [15].

Limits of Detection and Quantification

The limits of detection and quantification were evaluated from the concentration of analytes required to give a signal-to-noise ratio of 3 and 10 respectively to give regression equation, determination coefficients, and limits of detection and quantification of the various heavy metals.

From table 4, Water Sample A1 (untreated) had high heavy metal concentrations, with iron, nickel, and mercury showing notable concentrations. The average iron concentration was 180.136 µg/L, suggesting a stable iron content. Excessive levels can alter water taste, color, and odor, promote the growth of iron bacteria, and interfere with oxygen exchange, affecting aquatic life [16]. Iron in sediments, deposited from water columns and influenced by drilling muds, oil spills, and industrial discharges, can influence nutrient cycling and habitat quality for benthic organisms [17]. Monitoring is crucial, with sequential extraction methods and sediment quality guidelines helping evaluate iron-related risks to ecosystems.

Nickel concentration was 19.546 µg/L, suggesting moderate contamination or nickel presence. Nickel can bioaccumulate in aquatic food webs and cause skin dermatitis. It can disrupt benthic communities and interfere with nutrient cycling, especially in low-energy environments like lakebeds and wetlands [18].

Cadmium concentration was 18.451 µg/L, indicating consistent levels. Mercury concentration is 0.941 µg/L, suggesting fluctuating environmental conditions or measurement uncertainty. High mercury levels impair reproduction, growth, and behavior in fish and aquatic invertebrates [19]. Human health concerns include cognitive deficits, motor impairments, and kidney damage. Mercury in sediments is deposited from oil drilling residues, produced water discharge, atmospheric deposition from fossil fuel combustion, and runoff from industrial and artisanal gold mining operations [20]. Lead concentration was moderate at 30.326 µg/L, with consistent measurements across runs. The high heavy metal levels in water sample A1 suggest potential contamination, requiring further investigation into potential sources. The variability in mercury concentration was higher than other metals, suggesting fluctuating environmental conditions or measurement uncertainty. The iron concentration was below the WHO limit, but excessive exposure can cause staining, metallic taste, and potential biofouling of pipelines. Nickel concentration was also below the WHO limit, but prolonged exposure could lead to bio-accumulation in the body, potentially causing dermatitis and allergic reactions. Cadmium concentration was significantly higher than the WHO limit, causing kidney damage, bone demineralization, and cancer. Mercury is within the WHO safe limit, but bioaccumulation risks in the food chain are of concern. Lead concentration is far above the WHO guideline, posing severe health risks, especially for children and pregnant women. Therefore, the water is fairly unsafe for drinking or domestic use without proper treatment.

From table 5, Biochar treatment significantly reduced the concentration of heavy metals in water sample A2, (duplicate sample of A1) including iron, nickel, cadmium, and lead. The treatment did not detect any iron or nickel levels, suggesting that the concentration was below the detection limit. Cadmium concentrations were also reduced to undetectable levels. The mercury concentration decreased from 0.941 µg/L in sample A1 to 0.697 µg/L in sample A2, with a 4.9% RSD. Lead concentration was not detected, indicating that biochar treatment likely removed it from the water sample. The study suggested that biochar was more effective at removing certain metals than others, with mercury being the only detectable metal. Biochar was found to be highly effective for removing iron, nickel, Cadmium, and lead (100% efficiency), leaving a minimal trace of nickel (0.363 µg/L). However, it only had a 26% efficiency for mercury removal, leaving 0.697 µg/L within the WHO safe limit.

From table 6, Water Sample B1 (Untreated) has lower heavy metal concentrations compared to sample A1, with iron levels significantly lower and cadmium present at very low levels. The RSD was 35.5%, suggesting unstable iron levels. The RSD (6.4%) is relatively low, indicating moderate consistency. 111Cd has a very low concentration of cadmium, showing negligible contamination. The RSD was 50.9% across all the runs. 202Hg was slightly lower than in sample A1, but still detectable, with a low RSD of 5.7%. 208Pb was not detected, suggesting lead was not present or below the detection threshold. The sample exhibits moderate variability in some metals, particularly cadmium and iron. Sample B1 is significantly safer than sample A1, with all heavy metal concentrations within WHO limits. The iron (Fe) concentration was within WHO limits, indicating no significant risk. The nickel (Ni) concentration was significantly below the WHO limit, indicating low contamination. The cadmium (Cd) level was also below WHO limits, indicating safe water quality. The mercury (Hg) concentration was within the safe limit but should be monitored to prevent bioaccumulation risks. Lead was not detected in sample B1, complying with WHO guidelines.

From table 7, Biochar treatment significantly improved water quality in Sample B2, a duplicate of Sample B1. The treatment removed iron, and cadmium from the water, with some nickel remaining. However, nickel and mercury were reduced but not eliminated, suggesting that biochar was less effective at removing these metals. The RSD was 13.5%, indicating variability in measurements. The treatment also reduced cadmium to undetectable levels, with a reduction of 0.565 µg/L, lower than the original 0.688 µg/L in sample B1. Lead was also absent in the sample B1. The overall biochar treatment was effective in reducing heavy metal concentrations in water.

CONCLUSION

The study analyzed water samples A1, A2, B1, and B2 to determine the effectiveness of biochar treatment in removing heavy metals from water. Sample A1 contained significant concentrations of iron, nickel, cadmium, mercury, and lead, with lead, iron, and nickel being the most prominent contaminants. These concentrations were of concern as they exceed environmental safety levels for some heavy metals and indicate potential instability in the water quality. In Sample A2, biochar treatment effectively removed iron from the water sample, as no detectable iron was found in A2. Biochar treatment also eliminated detectable levels of nickel in this sample, which was a positive outcome as cadmium is highly toxic. Mercury levels were reduced, though not entirely eliminated, indicating that biochar was highly effective in removing most of the selected heavy metals but may require further optimization for mercury removal. In Sample B1, the concentration of iron, nickel, cadmium, and lead was significantly reduced compared to A1, suggesting that B1 may be less contaminated with iron. The variability (RSD 35.5%) was high, indicating significant fluctuations in iron levels across the runs. The RSD (6.4%) was moderate, indicating reasonable consistency across runs. The high RSD (50.9%) suggests that measurements for cadmium was inconsistent. The reduction in mercury concentration suggests that biochar treatment had a positive effect on mercury removal, but it is still detectable at reduced levels. In Sample B2, biochar treatment was effective in removing iron, cadmium, and lead from B2, resulting in undetectable concentrations of these metals. Nickel and mercury were reduced, though not fully eliminated, showing that biochar was less effective in removing these metals compared to others. The moderate variability in nickel levels indicated that biochar treatment may not always provide consistent results for every metal, and further optimization may be needed to improve its efficiency for mercury and nickel removal. The results showed that while biochar is highly effective at removing some metals, it was less efficient for others like mercury and nickel. Further optimization or combined treatment methods may be needed for these metals. Iron, Cadmium, and Lead were almost completely removed by biochar treatment, indicating that biochar is very effective for these metals. The presence of Nickel, Mercury, Lead, and Cadmium at significant levels in the untreated water samples suggests that these water sources could be hazardous to human and environmental health, particularly as these metals can accumulate in living organisms and cause toxic effects even at low concentrations. Biochar treatment significantly improves water quality by reducing the levels of most of the selected toxic metals, making it an effective and eco-friendly approach to heavy metal removal. Future considerations should include optimizing biochar performance for Mercury and Nickel, possibly by combining biochar with other treatment methods. Regular monitoring and testing of treated water are essential to ensure that all contaminants are sufficiently removed and that treated water meets environmental and health standards.

Recommendations

Biochar, a water treatment agent, has shown promise in removing iron, nickel, cadmium, and lead. However, further optimization for mercury and nickel is needed, possibly combining it with other technologies for maximum water treatment. Regular monitoring of heavy metals in water sources is crucial, especially for lead, cadmium, and mercury, which can have severe health and environmental consequences. Biochar treatment should be a standard method for improving water quality in contaminated areas. Further research should focus on enhancing biochar's ability to remove nickel and mercury, and long-term studies should assess the sustainability and reusability of biochar for multiple cycles of heavy metal removal. Public health campaigns should be conducted in regions with water contamination concerns to raise awareness about the risks of heavy metals and the potential benefits of biochar treatment.

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CITE AS: Lasuba Joseph Chaplain, and Ampaire Wycliffe (2025). Assessment of Levels of Selected Heavy Metals and Their Removal in Water Using Biochar Adsorption along Ggaba Market. Research Output Journal of Biological and Applied Science 5(3):1-11.
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