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Use of bamboo biochar for heavy metals removal from wastewater effluents in stabilization ponds in Embu town, Kenya

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ABSTRACT

Rapid population growth and expansion of industries have led to increase in the presence of heavy metals in wastewater. Irregular discharge of such wastewater with little or no treatment has been rampant in developing countries. Exposure to heavy metals has been associated with stunted growth and development, acute and chronic respiratory effects, cancerous effects, autoimmunity and even death. Technological solutions for heavy metal removal that are affordable, environmentally benign, and simple to use are needed to address these challenges. This study investigated the effectiveness of two differently modified bamboo biochar in removal of selected heavy metals from effluents in wastewater stabilization ponds (WSPs) in Embu town, Kenya. One modification involved pyrolysis hourly at 250° C, then at 350°C, and lastly at 500°C and labelled AC whereas the other involved chemical activation using potassium hydroxide followed by pyrolysis and referred as AC+KOH. Sampling of wastewater along the treatment processes was conducted during the wet and dry season, totalling to forty-two samples. Atomic absorption spectrophotometer was used to analyse the amounts of Pb2+, Cd2+, and Cu2+ ions in the WSPs effluents. Mean concentrations ranged from 0 to 0.097 ppm, 0.004 ppm, and 0.355 ppm of Cu2+, Cd2+ and Pb2+ ions respectively. In Kenya, maximum allowable limits for discharge into public water for Cu2+, Cd2+ and Pb2+ ions are 1 ppm, 0.01 ppm, and 0.01 ppm respectively. Microsoft Excel, SPSS version 26 and R studio was used for statistical analysis. The Pb2+ ions removal effectiveness using AC ranged from 86% to 100%, whereas treatments using AC+KOH ranged between 72% to 90%. There was a significant difference, the p-value was 0.04655 < 0.05 between the differently modified bamboo biochar. Findings from the study indicates effectiveness of bamboo biochar in treating wastewater contaminated with Pb2+ ions, with AC performing better than AC+KOH.

Introduction

Adequate sanitation, hygiene, and safe water are paramount for health and socio-economic advancement. Shockingly, 42% of domestic wastewater remains improperly managed worldwide, disproportionately affecting low-income areas as in developing nations where on average treat only 8% of domestic and industrial wastewater (UN Water, 2023). Illicit disposal of untreated wastewater into drainage channels (Geoffrey, 2020), often lacking adequate treatment, is preva-

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lent (Sussy et al., 2020). Hazardous waste from hospitals, small-scale mining, and auto repair shops compounds this issue alongside household and human waste (Edokpayi et al., 2021). These actions persist despite the existence of standards set by KEBS, EAS, USEPA, and WHO. Drinking and agricultural water sources containing effluents pose health risks. The dearth of freshwater has led to the perilous use of untreated wastewater for irrigation, facilitating the accumulation of toxic substances, including heavy metals, in the environment. These substances enter the food chain, causing adverse effects on human health. Heavy metals are non-degradable pollutants that have deleterious effects even in trace amounts for example, cadmium (Cd2+) and lead (Pb2+) ions are linked to respiratory and cancerous effects (Engwa et al., 2019). However, some are essential for physiological functions for instance, copper ions (Cu2+) but still can be toxic in high doses (Showkat et al., 2019). Proper wastewater treatment and management is thus crucial for obtaining clean water and safeguarding the environment.

Conventional wastewater treatment methods encompass primary, secondary, and advanced tertiary techniques. Primary treatment removes suspended solids, oils, and grease and grit via sedimentation. Secondary methods, like wastewater stabilization ponds, activated sludge, anaerobic reactors and artificial wetlands, focus on biological treatment, whereas tertiary approaches address nutrient removal and employ ultrasonication, ultraviolet treatment, and ozonation (Miruka, 2016; Kesari et al., 2021). Amongst these, wastewater stabilization ponds stand out for their cost-effectiveness due to their minimal technological investments and low operation and maintenance costs as reported by (Desye et al., 2022). Hence emerges as the predominant technology for global wastewater treatment, as reported by Desye et al. (2022). Despite their prevalence, many conventional wastewater methods face significant challenges, particularly in accommodating increased wastewater inflows without a corresponding expansion of infrastructure. This limitation hampers their ability to meet the growing demand for achieving lower levels of heavy metals in the final effluent (Ruxandra et al., 2020). The financial difficulties associated with advanced approaches pose obstacles to keeping pace with the escalating requirements for efficient and environmentally sound wastewater treatment. In Kenya, most final effluents do not meet EMCA, 2006 standards (Flory et al., 2021).

To combat heavy metal contamination and conserve the environment, exploring nanotechnology looks promising. Nanotechnology offers efficient and affordable wastewater treatment systems, utilizing bioactive nanoparticles, nanostructured catalytic membranes, and molecularly imprinted polymers to remove toxic metal ions and disease-causing bacteria (Lamaming et al., 2020; Gupta et al., 2021). Additionally, activated carbon production offers a versatile adsorption technique. Commercial activated carbon boasts a large surface area and functional groups for pollutant adsorption, albeit its dependence on non-renewable resources poses environmental concerns (Gupta et al., 2021; Yang et al., 2022). Adsorption using natural renewable waste materials and the concept of green chemistry looks attractive unlike the non-renewable fossil resources. This is justified by several factors such as possibility of mass production at affordable cost, inexhaustible supply of the carbon materials and the even distribution throughout the globe unlike use of fossil fuels (Sharma et al., 2018). More so, curbing the energy lost and the air pollution exhibited when such waste is burnt. Within this context, bamboo emerges as a promising adsorbent.

Bamboo rapid growth, sometimes at a rate of two inches per hour, and abundance make it an attractive resource for sustainable practices (Sharma et al., 2018). Globally, bamboo covers over 31 million hectares, with significant portions in China, Brazil, and India (Wang et al., 2015). Two widespread kinds found in Africa, Oxytenanthera abyssinica and Bambusa vulgaris, reach maturity heights of about 8–20 meters. Bamboo

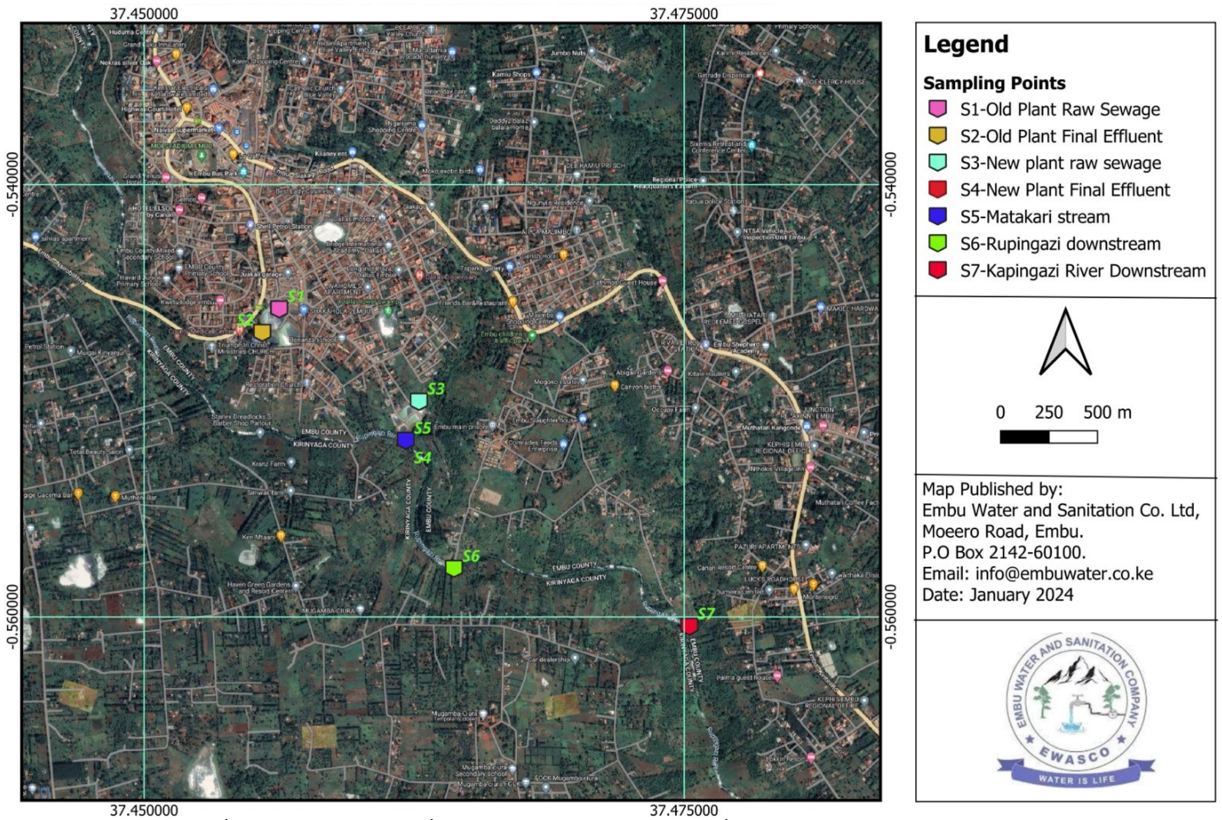

Figure 1: *Sampling Points at Embu Sewage Treatment Plant*

is widely accessible and, if used, would help impoverished rural populations in Africa right away (Ogutuga et al., 2016). It holds diverse applications, from protecting watersheds to construction materials due to its mechanical and thermal characteristics (Sahoo et al., 2021).

Bamboo's utilization as a raw material for wastewater treatment has gained momentum recently, leading to the creation of diverse adsorbents like bamboo biochar, bamboo-activated carbon, and bamboo aerogel (Lamaming et al., 2022). Bambusa vulgaris, Moso, Ma, and Gigantochloa albociliata are among the bamboo species used as raw materials. Bamboo-based adsorbents stand out due to their remarkable surface area to mass ratio, enabling them to effectively absorb materials ranging from chemicals, minerals, and humidity to odours and even electromagnetic waves (Lamaming et al., 2022).

In wastewater treatment, Yuan et al. (2021) investigated agricultural bamboo leaf waste's potential as a carbon precursor for Cu-Al/biomass fibre adsorption. Their study demonstrated exceptional removal of ammonia nitrogen pollutants from domestic wastewater, surpassing commercial activated carbon in total ammonia nitrogen removal efficiency. Understanding bamboo biochar adsorption mechanisms is pivotal for enhancing its efficacy. In their adsorption studies, Queiroz et al. (2020) used 1 g L-1 of adsorbent in an aqueous solution containing Pb2+, Fe2+, and Mg2+ metal ions at a concentration of 30 mg L-1 for one hour while stirring. It was found that the adsorbent's surface chemistry was more important for metal adsorption than the textural characteristics of the material. The enhanced adsorption onto the surfaces of acid-modified activated carbon was ascribed to the greater ionic radius of Pb2+ in comparison to Fe2+ and Mg2+, as well as the harder Lewis acid characteristic, which was responsible for the improved performance.

Biochar effectiveness in the removal of heavy metals, antibiotics, dyes, and microbes is achieved through a variety of mechanisms. These mechanisms including π-π surface complexation, electrostatic interaction, pore filling, co-precipitation, ion exchange, diffusion, hydrophobic interaction, and hydrogen bonding (Upadhyayula & Chaudhary, 2021). The potential for recycling bamboo-based adsorbents is underscored in Lamaming et al. (2022), suggesting efficient regeneration techniques can reduce environmental impact, rendering bamboo biochar an eco-friendly heavy metal removal option. However, despite the potential of biochar, there are still research gaps that demand further attention to establish it as a universal material for wastewater treatment.

Embu Water and Sanitation Company (EWASCO) employs wastewater stabilization ponds technology in Embu County, but its limitations in heavy metal removal are evident in recent studies showing higher-than-permissible levels of copper, cadmium, chromium and lead in sewage effluents (Sussy et al., 2020). This study examined the effectiveness of chemically and physically activated bamboo biochar in removing heavy metal ions (Cu2+, Cd2+, Pb2+) from Embu WSPs effluent in Embu Town, Kenya, bridging knowledge gaps and contributing to sustainable wastewater treatment practices. By addressing the deficiency in current wastewater treatment methods and leveraging the natural properties of bamboo, this research could contribute to a more efficient and sustainable approach to wastewater management, ensuring cleaner water resources and a healthier environment.

Materials and Methods

Study Area.

The research was conducted in Embu Town, situated approximately 120 kilo meters northeast of Nairobi, in the vicinity of Mount Kenya, with geographical coordinates at Latitude: 0° 31' 52.03" N and Longitude: 37° 27' 2.20" E. Embu Town is serviced by two sewerage plants both located at Dallas Estate. A 1972 constructed old facility and rehabilitated over the years and currently having four wastewater stabilization ponds and a more recent one constructed in 2021 featuring six wastewater stabilization ponds organized in two parallel series. Biochar production was done at Meru University of Science and Technology, Chemistry Laboratories in Meru County whereas heavy metal tests were done at Chuka University in Tharaka Nithi County. Sampling of wastewater samples were done during the rainy and dry seasons. A total of forty-two samples were collected in seven designated points, figure 1.

Sampling and Digestion of Samples.

Wastewater samples were carefully collected in each one-litre polypropylene bottles, pre-acid washed to eliminate contamination. Additionally, to inhibit precipitation and microbial activities during transportation, each sample was preserved in acidic conditions. This involved adding 1.5ml of concentrated nitric acid to one litre of each sample. The preserved samples were then transported to Chuka University laboratories for heavy metal analysis.

200 ml of both the samples and blanks were subjected to digestion using 5 ml of concentrated nitric acid, followed by filtration and subsequent dilution to a final volume of 100 ml with distilled water. The resulting filtrate served as the basis for the subsequent heavy metal analysis.

Prepared biochar and corresponding blanks were digested using 20 ml of aqua regia for each 2.5g, followed by filtration and dilution to 50 ml using distilled water. The resulting filtrate served as the basis for the subsequent heavy metal analysis.

Production of Bamboo Biochar

Bamboo (Bambusa vulgaris) stems were obtained from Mt Kenya forest. The stems were cut into small pieces using a cutting machine. The pieces were washed thoroughly with distilled water before being dried out in an oven for 24 hours at 105°C. The first lot of bamboo pieces was pyrolyzed in a furnace at 250°C, then increased to 350°C, and eventually to 500°C every hour, fol-

$$Pb^{2+}\text{ removal }(\%) = \frac{Pb2+\ before\ treatment - Pb2+\ after\ treament}{Pb2+\ before\ treatment}\ x\ 100\% \qquad (1)$$

Equation 1: *Pb2+ removal from biochar formula*

lowed by a 24-hour chilling period in a desiccator (physical activation) and referred to as AC. The second lot was first activated using potassium hydroxide (KOH) pellets in a ratio of two to one (Bamboo pieces: KOH). This was accomplished by soaking for four hours and baking dry for twelve hours at 150°C (chemical activation). The chemically activated bamboo pieces then underwent pyrolysis same way as the first, followed by a 24-hour cooling period in a desiccator. After which regular rinsing in distilled water and 0.1M hydrochloric acid was done until the washing was free of base medium and the pH fell to 5. Drying in an oven at 105°C for 12 hours followed and biochar referred to as AC+KOH. The biochar was then crushed using mortar and pestle to powder form as prescribed by (Gimba et al., 2004) making it ready for use.

Analysis of Heavy Metals

Atomic adsorption spectrophotometer (AAS) PG 990 series was set up. Standard solutions of Cu2+, Cd2+, and Pb2+ ions were prepared at 1000 ppm concentrations using copper, cadmium and lead salts, followed by serial dilution for various concentrations. The standard solutions were run to obtain the absorbances and calibration curves were drawn. Analysis of heavy metal ions present in WSPs raw sewage, effluents, stream and river water samples were run and absorbances obtained. The respective concentrations were derived from interpolation of absorbances in the calibration curves. The biochar was also assessed for heavy metal ions content before usage.

Statistical Analysis

Samples were run in triplicate and mean value and standard deviations calculated. Data were analysed using Microsoft Excel, SPSS version 26, and R Studio. The least significant difference at a 5% level of significance in competitive adsorption of Pb2+ ions from WSPs effluents by the differently modified bamboo biochar, that is, AC+KOH and AC was also calculated.

Heavy Metal Removal using Bamboo Biochar

One gram of activated bamboo biochar was added into 100ml of samples that indicated presence of Pb2+ ions and swirled (200 revolution per minute using orbital shaker) for two hours and then filtered through Whatman filter paper No 1. The filtrate was then run for residue Pb2+ ions determination using AAS PG 990 series. The efficacy of the modified biochar on Pb2+ removal was calculated as shown in equation 1.

Results

Concentration Levels of Cu2+, Cd2+ and Pb2+ Ions in the WSPs Effluents

Table 1 and 2 shows mean concentration levels of Cu2+, Cd2+ and Pb2+ ions in all the sampling sites during the wet season and dry season respectively. The seven sampling points were found to have varying concentration of the heavy metals under study. During the wet season, the order of the heavy metal concentrations was found to be lead>copper>cadmium whereas during the dry period it was copper>lead>cadmium.

Cu2+ ions levels ranged from no detection to 0.097±0.006 ppm and were below the EMCA (2006) maximum discharge level of 1ppm during wet and dry season. Similarly, Cd2+ ions levels were within the guideline values required for discharge into public water which is 0.01ppm during both the wet and dry season. Cd2+ ions concentrations ranged from no detection to 0.004±0.001 ppm. However, Pb2+ ions levels ranged from no detection to 0.355±0.002 ppm against a standard of 0.01ppm required for dis-

Source	Sample Label	Cu^{2+}, ppm	Cd^{2+}, ppm	Pb^{2+}, ppm
Raw sewage old plant	S1	0.026±0.002	Not detected	0.266±0.034
Final effluent old plant	S2	Not detected	Not detected	0.355±0.002
Raw sewage new plant	S3	0.032±0.001	Not detected	0.284±0.012
Final effluent new plant	S4	0.035±0.001	0.002±0.000	Not detected
Matakari stream	S5	0.033±0.001	0.001±0.000	Not detected
Rupingazi River downstream	S6	0.018±0.001	Not detected	0.284±0.003
Kapingazi River downstream	S7	0.017±0.000	Not detected	0.147±0.017

Table 1: *Concentration Levels of Cu2+, Cd2+ and Pb2+ Ions before Treatment during Wet Period.*
Guideline maximum level to be discharge into public water; Cu2+: 1ppm, Cd2+: 0.01ppm, Pb2+: 0.01ppm (EMCA, 2006)

Source	Sample Label	Cu^{2+}, ppm	Cd^{2+}, ppm	Pb^{2+}, ppm
Raw sewage old plant	S1	0.097±0.006	0.001±0.000	0.018±0.006
Final effluent old plant	S2	0.029±0.006	0.002±0.002	Not detected
Raw sewage new plant	S3	0.083±0.002	0.003±0.000	Not detected
Final effluent new plant	S4	0.038±0.006	0.003±0.000	Not detected
Matakari stream	S5	0.035±0.006	0.002±0.001	Not detected
Rupingazi River downstream	S6	0.038±0.003	0.004±0.000	Not detected
Kapingazi River downstream	S7	0.027±0.001	0.004±0.001	Not detected

Table 2: *: Concentration Levels of Cu2+, Cd2+ and Pb2+ Ions before Treatment during Dry Period*
Guideline maximum level to be discharge into public water; Cu2+: 1ppm, Cd2+: 0.01ppm, Pb2+: 0.01ppm (EMCA, 2006)

charge into public water. There was sufficient Pb2+ removal at the new plant during both dry and wet season. Thereby, preventing potential contamination of natural water bodies as seen in the safe levels in Matakari stream. More so, there was sufficient Pb2+ removal at the old plant during the dry season. In contrast, higher levels of Pb2+ ions in the final effluent than the raw sewage of old wastewater treatment plant during the wet season were found. Rupingazi river where the effluent is discharged, contamination of Pb2+ ions was as well detected during wet season unlike during dry season. Kapingazi river does not receive discharge from either of the plant but still Pb2+ contamination was found during the wet season.

Concentration Levels of Cu2+, Cd2+ and Pb2+ Ions in the Biochar

Table 3 shows mean concentrations levels of Cu2+, Cd2+ and Pb2+ ions in the two differently prepared biochar's before use.

The levels of Cu2+, Cd2+ and Pb2+ ions were higher in the AC biochar than in the AC+KOH. Though Cu2+ ions in the AC were detected, there are no set standards of Cu2+ ions requirement for water treatment chemicals. Cd2+ ions, in the AC biochar was detected and had mean concentration 0.034±0.001 ppm which were within the set standards of 1 ppm of Cd2+ ions for water treatment chemicals (KS 1290-4:2007). Similarly, Pb2+ levels in the AC were within the set standards of 4 ppm (KS 1290-4:2007) for water treatment chemicals. Mean concentration of Cu2+ in the AC+KOH was 0.3±0.001 ppm whereas its mean concentration of Cd2+ was at 0.029±0.000 ppm which were within the acceptable ranges required for water treatment chemicals. The AC+KOH biochar

Sample Label	Cu^{2+}, ppm	Cd^{2+}, ppm	Pb^{2+}, ppm
AC	0.671±0.005	0.034±0.001	0.078±0.011
AC+KOH	0.3±0.000	0.029±0.000	Not detected

Table 3: *Concentration Levels of Cu2+, Cd2+ and Pb2+ Ions in the Biochar before Use*
Maximum level for water treatment chemicals; Cu2+: Not indicated, Cd2+: 1ppm, Pb2+: 4ppm (KS 1290-4:2007)

	Sample Label	Before treatment, Pb^{2+}, ppm	After treatment with AC+KOH, Pb^{2+}, ppm	% Removal	After treatment with AC, Pb^{2+}, ppm	% Removal
Raw sewage old plant	S1	0.266±0.034	0.073±0.005	73	0.036±0.004	86
Final effluent old plant	S2	0.355±0.002	0.037±0.003	90	0.033±0.009	91
Raw sewage new plant	S3	0.284±0.012	0.079±0.004	72	0.018±0.022	94
Final effluent new plant	S4	Not Detected				
Matakari stream	S5	Not Detected				
Rupingazi River downstream	S6	0.284±0.003	0.057±0.002	80	Not Detected	100
Kapingazi River downstream	S7	0.147±0.017	0.016±0.009	89	0.014±0.01	90

Table 4: *Performance of Two Differently Activated Biochar in Pb2+ Ions Removal from WSPs Effluents*

did not contain Pb2+ ions. Both AC and AC+KOH biochar therefore conformed to required levels of Cu2+, Cd2+ and Pb2+ ions for water treatment. The levels of the various heavy metals found in the biochar could be attributed to the soils from which bamboo grew.

Differently Modified Bamboo Biochar on Competitive Adsorption of Cu2+, Cd2+ and Pb2+ ions from WSPs Effluents in Embu Town.

Table 4 shows performance of two differently modified bamboo biochar, AC+KOH and AC in Pb2+ ions removal from WSPs effluents at Embu town. Copper and Cadmium were in low levels as well as not detected hence the experiment continued with only lead ions removal.

Treatment using AC+ KOH biochar resulted in 73% removal of Pb2+ ions at S1 which was the raw sewage at old plant whereas AC biochar treatment resulted to 86% removal. At S2 which was the final effluent of old plant, which had the highest levels of lead ions, the AC+ KOH treatment resulted in 90% removal, while AC treatment resulted in 91% removal. Raw sewage at new plant, S3, resulted to significantly lower removal of 72% on using AC+ KOH compared to 94% achieved on using AC. For S4, final effluent new plant and S5, Matakari stream water samples, the concentration of Pb2+ ions were below the detection limit and therefore treatment was not required.

More so, AC+ KOH treatment achieved 80% lead ions removal at S6, Rupingazi river downstream water whereas AC treatment showed 100%, complete removal of lead ions. As with Sample S7, Kapingazi river water samples, and which had the lowest lead concentration levels, the AC treatment and AC+ KOH treatment performed at 90% and 89%, respectively

To establish if a significant difference existed between the differently modified bamboo biochar, AC+KOH and AC on competitive adsorption of Cu2+, Cd2+ and Pb2+ ions from WSPs effluents at Embu town, the Wilcoxon rank sum test, which is a non-parametric test was used. This was done by use of the percentage of $Pb2+$ ions removed. It was found that the value of $W = 22.5$, and the p-value was $0.04655 < 0.05$.

Discussion

Both old and new wastewater plants had Cu2+ ions levels that were within the Kenyan standards for discharge into the environment during dry and wet season. Likewise, concentrations of Cd2+ ions were within the guideline values required for discharge into public water. The results demonstrated levels that ranged from 0 to 0.097 ppm, 0.004 ppm against set standards of 1 ppm, 0.01 ppm for Cu2+ ions and Cd2+ ions respectively showing conformation.

However, Pb2+ ions levels ranged from no detection to 0.355±0.002 ppm against a set standard of 0.01ppm required for discharge into public water. There was sufficient Pb2+ ions removal at the new plant during both dry and wet season as well as at the old plant during dry season. The absence of Pb2+ ions in the new wastewater treatment plant final effluent is a promising sign of effective treatment process. Thereby, preventing potential contamination of natural water bodies as seen in the safe levels in Matakari stream. However, high levels of Pb2+ ions in the final effluent of old wastewater plant during the wet season showed lack of removal which may be source of contamination of Rupingazi as also reported by Sussy et al. (2020). Sussy et al. (2020), had found mean concentrations ranging 0.484–1.834 ppm, 0.015–0.353 ppm, and 0.011–2.123 ppm, of copper, cadmium, and lead in the sewage effluent respectively. The significant reduction of the heavy metals could be attributed to introduction of effective microorganism and azolla algae since 2022. The high levels of Pb2+ ions during wet period in the old wastewater plant could be attributed to runoff from garages nearby. Kapingazi River does not receive discharge from either of the plant but still some contamination was found depicting multiple sources of contamination other than discharge from WSPs effluents

The study demonstrated that bamboo biochar exhibits notable adsorption efficiency for heavy metal ions regardless of whether KOH was used as a modifier or not, the percentage removal values were significant and ranged between 72% to 90% and 86% to 100% respectively. Lack of attaining 100% performance of the biochar can be attributed to presence of other competitive ions for the adsorption sites.

The study's findings bear significant implications for Embu town's environment. As compared to findings by (Edokpayi et al., 2021), variations from set standards for discharge to environment were observed in the final effluent in different months of the year and in different weather patterns. Lead levels were significantly high during the wet season unlike the dry season whereas copper and cadmium were significantly low in both seasons. Notably, absence of lead ions in the new plant's final effluent signals effective treatment, averting contamination of water bodies like the Matakari stream. Similarly, higher lead levels in old plant's final effluent compared to raw sewage indicate accumulation over time, potentially contaminating the Rupingazi river. Detecting significant lead levels in Kapingazi river, despite receiving no effluent discharge, implies multiple lead sources, demanding source identification to mitigate environmental degradation.

The study reveals that bamboo biochar shows promise as an effective adsorbent for eliminating Pb2+ heavy metal ions from wastewater effluents in WSPs. The results demonstrate significant adsorption efficiency, both with and without KOH treatment, suggesting inherent qualities in bamboo biochar for efficient metal ion removal. The study suggest that bamboo biochar could serve as an eco-friendly solution for tackling heavy metal-contaminated WSP effluents in Embu town. Implementing this technology might enhance water quality and mitigate environmental pollution. Potential of bamboo as a promising adsorbent for the removal of heavy metals has also been recognized in earlier research by other authors. According to Thotagamuge et al. (2021), hazardous metal removal effectiveness for As, Pb, and Cr was over 96%. Chen et al. (2020), demonstrated its effectiveness in treating wastewater from industrial sources. More so, related study by (Yosef 2018) using bamboo biochar modified with KOH reported 99.8% lead removal in synthetic wastewater and 60% in industrial wastewater. Likewise, this study underscores the potential of bamboo biochar for heavy metal removal. In sum, the study's outcomes promise promising prospects for bamboo biochar in heavy metal removal, fostering a multidisciplinary approach toward wastewater treatment enhancement and environmental protection.

Conclusion and Recommendation

The study's results emphasize the potential risks associated with even low concentrations of heavy metals in the waste stream. These metals, though present at relatively low levels, can accumulate over time, posing threats to the ecosystem, aquatic life, and potentially human health. Considering the significance of natural water bodies as drinking and irrigation sources, pollution source identification measures are vital. The study showed that the WSPs in Embu town had done a commendable job in reducing the concentrations of Cu2+, Cd2+, and Pb2+ in the effluents to very low levels or below the detection limit. However, higher than permissible Pb2+ levels remained during the wet season in one of the wastewater treatment plants requiring advanced treatment.

The study concluded that bamboo biochar with or without KOH activation could be a viable and eco-friendly solution for remediating WSPs effluents contaminated with heavy metal, Pb2+ ions with the latter performing better.

The study recommends monitoring programs in the area be expanded to encompass exhausters discharging to the plants as well as storm water. More so, proposes bamboo biochar as a viable material for lead removal in addition to wastewater stabilization pond technology and therefore application on large scale is necessary.

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Conflict of Interest

The authors declare no competing interest associated with this publication.

References

Chen, L., Zhang, Y., & Liu, Z. (2020). Application of bamboo biochar in wastewater treatment: A review. Chemosphere, 246, 125740. https://doi.org/10.1016/j.chemosphere.2019.125740

Desye, B. D., Kiptum, C. K., & Tamooh, F. (2022). Wastewater stabilization ponds: A cost-effective solution. Water Science and Technology, 85(6), 1745-1757.

Edokpayi, J.N., Odiyo, J.O., Popoola, E.O. & Msagati, T.A.M., (2021). Evaluation of contaminants removal by waste stabilization ponds: A case study of Siloam WSPs in Vhembe District, South Africa.

Environmental Management and Co-ordination (Water Quality) Regulations, 2006.

Engwa, G. A., Ferdinand, P. U., Nwalo, F. N., & Unachukwu, M. N. (2019). Mechanisms and health effects of heavy metal toxicity in humans. IntechOpen.

Flory, K., Zulu, B., & Chen Hong –bin. (2021). The Analysis of Wastewater Treatment System Efficiencies in Kenya: A Review Paper

Geoffrey, O. A. (2020). The influence of wastewater on the environment: A case study of lead and mercury concentrations in Machakos. Environmental Monitoring and Assessment, 192, 519. https://doi.org/10.1007/s10661-020-08501-7

Gimba, C.E; Ocholi, O. & Nok, A. 2004. Preparation of activated carbon from agricultural wastes II. Cyanide binding with activated matrix from groundnut shell. Nig journal of scientific research. 4 (2): 106 – 110

Gupta, R. K., & Mishra, S. (2021). Applications of nanotechnology in wastewater treatment. Environmental Nanotechnology, Monitoring & Management, 15, 100441.

Huang, A., Bai, W., Yang, S., Wang, Z., Wu, N., Zhang, Y., Ji, N., & Li, D. (2022). Adsorption Characteristics of Chitosan-Modified Bamboo Biochar in Cd (II) Contaminated Water. Journal of Chemistry, 2022. https://doi.org/10.1155/2022/6303252

Kenya standard. Chemicals used for treatment of water intended for human consumption. Part 4: Calcium hypochlorite, KS 1290-4:2007.

Kesari, K. K., & Meena, R. (2021). Advanced tertiary treatment methods for wastewater. Journal of Water Process Engineering, 39, 101708.

Lamaming, J., Rasit, N., & Hashim, R. (2020). Nanotechnology for heavy metal removal. Materials Today: Proceedings, 36(2), 193-198.

Lamaming, J., Saalah, S., Rajin, M., Ismail, N. M., & Yaser, A. Z. (2022). A review on Bamboo as an adsorbent for removal of pollutants for wastewater treatment. International Journal of Chemical Engineering, 2022, 1–14. https://doi.org/10.1155/2022/7218759

Miruka, C. (2016). Wastewater treatment in Kenya using stabilization ponds. Journal of Water Sanitation and Hygiene for Development.

Ogutuga, D. B. A., Ongugo, P. O., & Owuor, B. (2016). Bamboo resources in East Africa: The case of Kenya and Ethiopia. In Bamboo: The plant and its uses (pp. 377-387). Springer. https://doi.org/10.1007/978-981-10-2554-4_16

Queiroz, E.F., Trovó, A.G., Nascimento, A.L.C., Silva, M.P., Santos, J.O., & Veloso, C.O. (2020). Production and characterization of activated carbon from acai seeds and its application for metal ions removal from aqueous solutions. Journal of Hazardous Materials, 381, 120976.

Roshan Thotagamuge, Muhammad Raziq Rahimi Kooh, Abdul Hanif Mahadi, Chee Ming Lim, Masanizan Abu, Abigail Jan, Alifatul Haziqah Abu Hanipah, Yong Yung Khiong, Amanina Shofry, Copper modified activated bamboo charcoal to enhance adsorption of heavy metals from industrial wastewater, Environmental Nanotechnology, Monitoring & Management,Volume 16,2021,

Ruxandra, A. S., Radu, V., & Sandulescu, D. (2020). Financial constraints in conventional wastewater treatment. Journal of Environmental Protection, 11(4), 380-394.

Sahoo, B., Banerjee, M., Sahoo, D. R., & Sharma, B. (2021). Bamboo: A sustainable resource for green energy production and environmental conservation. Renewable and Sustainable Energy Reviews, 140, 110754. https://doi.org/10.1016/j.rser.2020.110754

Sharma, B., & Gatoo, A. (2018). Rapid growth of bamboo for sustainable development. Science Advances, 4(7), eaas9276.

Showkat., Ahmad., & Bhat; Showkat & Hassan; Tehseen & Majid; Sabhiya. (2019). Heavy metal toxicity and their harmful effects on living organisms-a review. 10.32553/jmsdr

Sussy, G., Tan, H., & Lee, J. (2020). Illicit discharge of untreated wastewater in developing countries. Journal of Environmental Management, 245, 128-135.

UN Water., (2023). Report on the state of wastewater management. United Nations.

Upadhyayula, S., & Chaudhary, A. (2021). Biochar as a green solution for heavy metal removal in wastewater treatment. Journal of Environmental Chemical Engineering, 9(1), 105007.

Wang, J., Xu, Q., & Liu, W. (2015). Bamboo biochar for the removal of fluoroquinolone antibiotics from wastewater: Performance and mechanism. Journal of Hazardous Materials, 284, 116-124. https://doi.org/10.1016/j.jhazmat.2014.11.018

World Health Organization. (2006). Guidelines for the safe use of wastewater, excreta and greywater. WHO Press.

Yosef, A. W. (2018). Bamboo Based Activated Carbon for Removal of Lead from Aqueous Solution.

Yuan, J., Zhu, Y., Wang, J., Liu, Z., Wu, J., Zhang, T., Li, P., & Qiu, F. (2021). Agricultural Bamboo leaf waste as carbon precursor for the prepara-