Journal of Aquatic and Terrestrial Ecosystems
2(3)
Received: June 18, 2024
Accepted: July 25, 2024
Published: September 28, 2024

Removal of Selected Heavy Metals from the Water of the River Sosiani in Uasin Gishu County Using *Cynodon dactylon* (Couch Grass)

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Abstract

The management of heavy metal pollution in rivers is a growing concern due to the rapid pace of industrialization and urbanization. Rivers are especially susceptible to heavy metal contamination due to various human activities, such as industrial processes, agricultural runoff, mining operations and improper waste disposal. Several studies in Kenya have documented the alarming presence of elevated heavy metal levels in various rivers, raising concerns about environmental and public health impacts. A variety of methods and techniques have been developed and implemented to remove heavy metals from contaminated water however, several of these techniques are expensive. The potential of plants to serve as a bio adsorbent offers a sustainable solution for addressing heavy metal pollution in rivers. This research therefore investigated the efficacy of modified *Cynodon dactylon* grass as an adsorbent for removing lead (Pb^{2+}), manganese (Mn^{2+}), cadmium (Cd^{2+}) and chromium (Cr^{6+}) ions from Sosiani River water. Water samples were collected from three purposively selected sites along the Sosiani River in Uasin Gishu County, Kenya and the mean heavy metal concentrations were analysed using Atomic Absorption Spectroscopy (AAS). The batch adsorption experiments were conducted in triplicates for untreated and treated grass. The study also examined the impact of pH levels on adsorption by testing at pH levels of 5, 7 and 9. Data was coded into SPSS software version 20 and analysed using descriptive and inferential statistics. The results indicate that the mean concentration of Cr^{6+} and Pb^{2+} in the water samples were 1.49 mg/L and 1.61 mg/L respectively. Both metals ions exceeding the NEMA guideline. However, the concentration of Cd^{2+} and Mn^{2+} was found to be 0.002 mg/L and 0.05 mg/L which is below the NEMA recommended level. Further, the heavy metal concentrations in Sosiani River water samples varied significantly ($p<0.05$) across different locations. Also, the chemically treated *Cyanodon dactylon* grass exhibited a higher percentage of adsorption across all tested heavy metals compared to the untreated *Cyanodon dactylon* grass. Lastly, there was a higher adsorption efficiency for treated adsorbent at pH 5 compared to pH 9. These findings demonstrate the potential of *Cynodon dactylon* grass as an effective and more accessible alternative for river water purification. Further research is needed to optimize the conditions and modifications for enhanced adsorption performance.

Keywords: Adsorption, river water, heavy metals, *Cyanodon dactylon,* pH, purification

Journal ISSN: 2960-1118

Issue DOI: https://doi.org/10.69897/jatems.v2i3

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Funding: The author received no financial support for the research, authorship and/or publication of this article.

Data Availability Statement: The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

Competing interests: The authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Introduction

The sources of heavy metals in the environment are categorized into natural and anthropogenic origins (Zhang et al., 2012; Fang et al., 2019; Algül & Beyhan, 2020). Metals such as lead, mercury, cadmium, arsenic, chromium and others, are naturally occurring in the Earth's crust (Balali-Mood et al., 2021; Sharma & Sharma, 2022). They are released into the environment through processes such as volcanic eruptions, weathering of rocks, and erosion (Masindi, Mkhonza & Tekere, 2021). However, it is human activities that have significantly increased the presence and concentration of these metals in the environment which are harmful even at low concentrations (Cimboláková et al., 2019; Akenga et al., 2016; Maina, Wambu & Kituyi, 2023; Nyamora et al., 2023).

Anthropogenic sources of heavy metals include industrial processes, such as mining, smelting and manufacturing, where metals are extracted and processed for use in various products (Alloway, 2013; Mishra et al., 2019; Gautam et al., 2016). Utilization of fertilizers, pesticides and wastewater irrigation have been documented by Sandeep et al. (2019), Waseem et al. (2014), Yargholi and Azarneshan, (2014) to introduce metals like cadmium, arsenic, and lead into the soil and water systems. Combustion of fossil fuels in power plants, vehicles, and residential heating have also been reported to releases heavy metals like mercury and lead into the atmosphere (Munawer, 2018; Dökmeci, 2020). Urbanization and improper waste management further exacerbate the problem, as heavy metals can leach from landfills, electronic waste and untreated sewage into the surrounding environment

(Tariq & Mushtaq, 2023; Arya & Kumar, 2020).

Heavy metals are non-degradable by biological or physical processes and persist in soil for long periods, posing a significant environmental threat (Yan et al., 2020). Several studies have documented that plants absorb heavy metals from contaminated soil and water through their roots, leading to accumulation in edible parts such as fruits, vegetables, and grains (Sandeep et al., 2019; Akenga et al., 2020; Maina, Wambu & Kituyi, 2022). Elevated levels of heavy metals have been reported in kales (Maina et al., 2023), tomatoes (Maina et al., 2022), leafy greens like spinach (Singh et al., 2012), maize (Akenga, 2017; Olero et al., 2018) among other edible plants. The concentration of these metals in vegetables can vary depending on factors such as the type of vegetable, soil composition, irrigation practices, and proximity to pollution sources (Zwolak et al., 2019; Sandeep et al., 2019). Consuming vegetables with elevated levels of heavy metals can pose significant health risks, as these metals can accumulate in the human body over time, leading to various chronic conditions (Latif et al., 2018; Zhou et al., 2016). Additionally, animals that graze on contaminated vegetation or drink polluted water can accumulate heavy metals in their tissues, which can then be passed on to humans through the consumption of meat, dairy products, and seafood.

Heavy metals can be classified into essential and non-essential categories based on their roles in biological systems (Saad et al., 2014; Ali & Khan, 2018). Essential metals like copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) are necessary for physiological and biochemical processes in plants, but can become toxic in excess (Shahzad et al., 2018). On the other hand, non-essential metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are highly toxic and have no known function in plants (Bibi et al., 2023). These toxic metals can cause environmental pollution, disrupt plant physiological processes, reduce agricultural productivity and enter the food chain through crops (Angon et al., 2024). As they accumulate in the human body through biomagnification, they pose a serious threat to human health (Maurya & Malik, 2019; Sonone et al., 2020).

Heavy metals can enter human body through various routes of exposure, including dermal contact, ingestion and inhalation causing both acute and chronic health effects (Al Osman et al., 2019; Jyothi, 2020). Acute exposure to high levels of lead can result in symptoms such as abdominal pain, headaches, irritability, memory problems and muscle weakness (Samarghandian et al., 2021; Charkiewicz & Backstrand, 2020; Flora et al., 2012; Mehta et al., 2017). In severe cases, acute lead poisoning can lead to seizures, coma, and even death (Patrick, 2006; Hauptman et al., 2017). Chronic exposure to lower levels of lead have been documented to cause developmental delays in children, reduced cognitive function, behavioral issues and learning difficulties, hypertension, kidney damage and reproductive problems (World Health Organization, 2023). Chromium exists in several forms, with hexavalent chromium (Cr (VI)) being the most toxic (Saha et al., 2011; Azeez et al., 2021). Acute exposure to high levels of Cr^{6+} can cause severe skin irritation, ulceration, and respiratory problems, gastrointestinal distress, including asthma and bronchitis (Teklay, 2016; Junaid et al., 2016). Prolonged exposure has been linked to an increased risk of lung cancer, kidney and liver damage, as well as dermatological issues (Teklay, 2016). Manganese on the other hand is an essential trace element necessary for normal physiological function; however, excessive exposure can lead to toxicity (Santamaria & Sulsky, 2010). Acute manganese poisoning causes coughing, bronchitis and pneumonia while prolonged exposure leads to Parkinson's disease (Guilarte, 2010; Kwakye et al., 2015).

Rivers are especially susceptible to heavy metal contamination due to various human activities, such as industrial processes, agricultural runoff, mining operations, and improper waste disposal (Bukola et al., 2015; Chakraborty & Chakraborty, 2021), which pose substantial threats to human health (Tchounwou et al., 2012; Ungureanu & Mustatea, 2022; de Carvalho Machado & Dinis-Oliveira, 2023), aquatic ecosystems (Khayatzadeh & Abbasi, 2010; Gheorghe et al., 2017) and the overall quality of water resources.

In many developing countries, including Kenya, the management of heavy metal pollution in rivers is a growing concern due to the rapid pace of industrialization and urbanization. Several studies in Kenya have documented the alarming presence of elevated heavy metal levels in various rivers, raising concerns about environmental and public health impacts. For instance, Njuguna et al. (2017) assessed macrophyte, heavy metal, and nutrient concentrations in the Nairobi River and found significantly elevated levels of Cr, Pb, Fe, and Mn in the water. In another study, Mwangi (2013) examined the concentrations of selected heavy metals in tilapia fish, sediments, and water from the Mbagathi and Ruiru tributaries of the Athi River. The findings revealed significant contamination by metals, indicating a potential risk to both aquatic life and human consumers of fish from these waters. Therefore, due to heavy metals persistence in the environment, their potential for bioaccumulation and their dual nature of heavy metal toxicity both acute and chronic there is need to mitigate the risk of heavy metal ion exposure to humans and animals, it is imperative to extract them from places that have been polluted.

River Sosiani, located in Uasin Gishu County, Kenya, has been increasingly affected by heavy metal contamination, primarily due to industrial activities, hospitals and agricultural practices in the surrounding areas which are transported into the river through surface runoff, contaminating downstream water sources. Additionally, domestic waste and runoff from motor vehicle garages contribute significantly to the heavy metal load in the river. The rapid growth of the local population has exacerbated the accumulation of waste, including heavy metals, in the river system (Wasike et al., 2019). Studies have reported heavy metals pollution in river Sosiani (Jepkoech et al., 2013; Amadi, 2013; Shieunda et al., 2019; Masakha et al., 2017; Achieng et al., 2017). The presence of these metals in the river not only threatens the health of local communities who rely on the water for domestic and agricultural use but also endangers the aquatic life that depends on the river's ecosystem. Safe and clean water is vital for human development and well-being. Residents living along the Sosiani River rely on its water for drinking, cooking and agriculture among other various activities. However, few studies have been conducted to remove these metals from rivers especially river Sosiani.

A variety of methods and techniques have been developed and implemented to remove heavy metals from contaminated water, including physical (adsorption, membrane technology and ion exchange), chemical (electrokinetic technology, chemical precipitation and precipitation) (Alka et al., 2021) however, they are accompanied by drawbacks such as the production of additional pollutants or exorbitant expenses. Biosorption is an alternative approach to eliminating heavy metals from water that involves employing eco-friendly and cost-effective biomass. Recent research has focused on the use of natural and low-cost adsorbents derived from plants for the removal of heavy metals from water. Among these, *Cyanodon dactylon* (commonly known as couch grass) has attracted attention due to its widespread availability, eco-friendliness and effectiveness in binding heavy metals (Kumari et al., 2021). *Cynodon dactylon* is a prevalent natural weed grass in many parts of Kenya, making it a readily available and economical option. The potential of this plant to serve as a bioadsorbent offers a sustainable solution for addressing heavy metal pollution in rivers, particularly in regions like Uasin Gishu County, Kenya, where water contamination has been documented. Therefore, this study investigated the use of chemically treated *Cynodon dactylon* grass, a locally available material, for the adsorption of heavy metal ions (Chromium, Lead, Cadmium and manganese) from polluted Sosiani river water.

Materials and Methods

Study area

The study was conducted in River Sosiani which is situated in Uasin Gishu County, in the North Rift region of Kenya (fig 1). The County shares common borders with Trans Nzoia County to the North, Elgeyo Marakwet County to the East, Baringo County to the South East, Kericho County to the South, Nandi County to the South West and Kakamega County to the North West (Kimani, 2017).

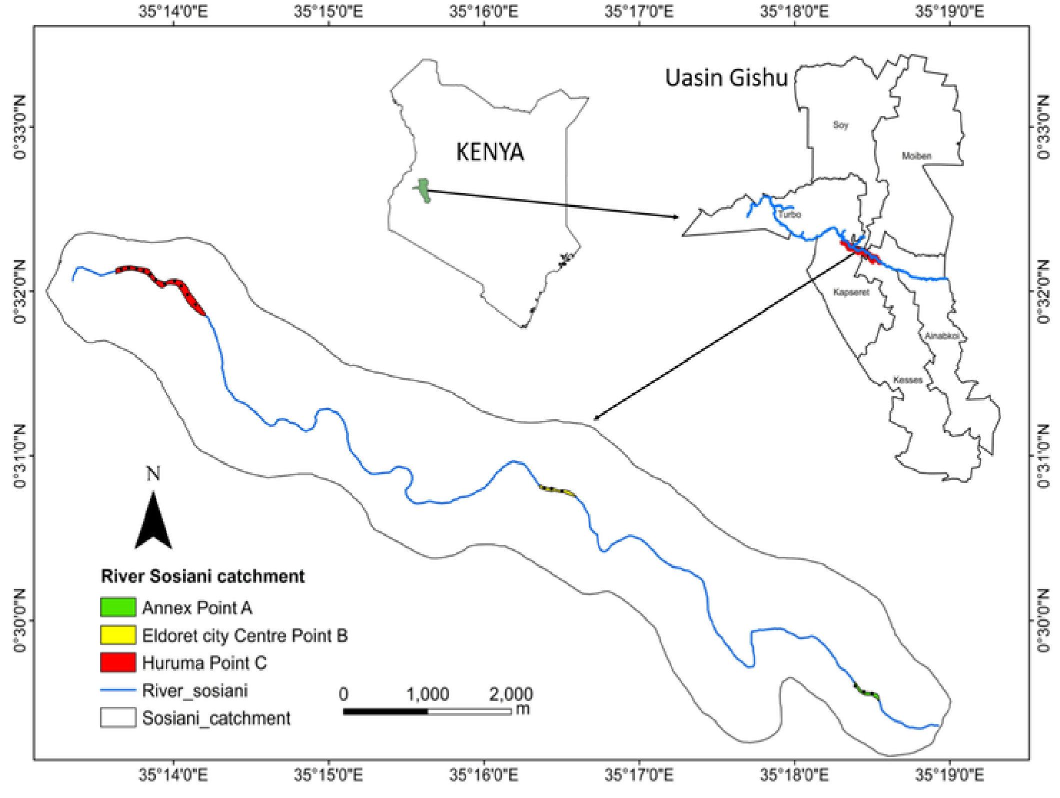

Figure 1: The study area map of River Sosiani
Source: Author, 2023

Covering an area of 3,345.2 Km^2, it is positioned between 0.52 latitude (0°31' 0N) and longitude 35.28 (35°16'60 E). Altitudes fall gently from 2,700m above sea level at Timboroa in the East to about 1,500m above sea level at Kipkaren in the West. The County is within the Lake Victoria catchment zone and therefore all the rivers from the County drain into Lake Victoria. Major rivers in the County include: Moiben, Sergoit, Kipkarren, Chepkoilel and Sosiani. The County's agricultural sector ranges from small-scale farming with low inputs to highly mechanized large-scale farming with total crop area covers 138,609 hectares. Key crops include maize, wheat, beans, Irish potatoes and various horticultural crops like passion fruits, coffee, macadamia and avocados. Livestock farming, particularly dairy and beef cattle of Ayrshire, Friesian and Sahiwal breeds, is prevalent, with dairy farming concentrated in Ainabkoi, Kapseret, and Turbo. Other significant social economic activities include industrial activities, small- and large-scale businesses as well as hospitals (Jepkoech et al., 2013).

Research design

This study employed an experimental research design and the research was conducted in three phases. In the phase one, water samples were collected from three predetermined sites along River Sosiani. These sites were selected based on proximity to potential sources of heavy metal contamination, such as industrial discharge points, agricultural runoff and urban effluent. In the second phase, adsorption experiments were conducted using batch processes. Chemically treated adsorbent materials were prepared from *Cyanodon dactylon* grass. The prepared adsorbents were then introduced into contaminated water samples to assess their ability to remove Pb^{2+}, Cr^{6+}, Cd^{2+} and Mn^{2+} ions. The percentage of adsorption was calculated to determine the efficiency of the adsorbents. Lastly, the study evaluated the impact of pH variation on the adsorption process. Different pH levels were tested to ascertain how the adsorption efficiency of *Cyanodon dactylon* changes with pH, thus providing data into optimal conditions for maximum heavy metal removal.

Cyanothon dactylon grass collections and Pre treatments

The mature *Cyanodon dactylon* (couch grass) was collected from areas within Uasin Gishu County, in regions with minimal industrial or agricultural pollution to avoid any pre-existing contamination by heavy metals. Collection sites was chosen based on accessibility and abundance of the grass. The grass was harvested manually using clean, stainless-steel tools to prevent contamination. After collection, the grass was placed in clean polyethylene bags, labeled and transported to the laboratory. At the University of Eldoret chemistry laboratory, grass was rinsed thoroughly with tap water, followed by a final rinse with deionized water to remove any dirt, dust or external impurities. Then air-dried at room temperature for 24 hours to remove excess moisture and cut into small pieces. The cut pieces were and soaked in boiling water for about 30 minutes to soften the adsorbent then was oven-dried at 105°C for 24 hours then grass allowed to cool to room temperature in a desiccator to avoid moisture uptake from the atmosphere. Once dried, the grass was grounded into a fine powder using a mechanical grinder then be sieved through a 100-mesh sieve (150 μm) to obtain a uniform particle size. About 500 grams of the sieved powder was stored in clean, airtight labeled containers to prevent contamination and moisture absorption. To enhance the adsorption capacity of the *Cyanodon dactylon* powder, a chemical modification process was undertaken. A portion of the *grass* powder was soaked in 0.5M KOH for 24 hours. After the treatment, the mixture was filtered and the residue was rinsed with 0.5M HCl before washing with distilled water. It was left in distilled water for 2 to 3 hours during which the water was changed several times until the pH of filtrate remained constant (pH 5). Then oven-dried at 105°C for 24 hours and stored in an airtight container.

Water sampling and pretreatment

Water samples were collected from three purposively selected sites along the Sosiani River in Uasin Gishu County, Kenya. The sampling sites were selected based on their proximity to industries (Kenya Co-operative Creameries Ltd. (KCC), Timber Treatment International (TTI), Corn Products Company (CPC), Ken Knit, Rupa and Raiply), hospitals, Jua Kali light industries, agricultural runoff and urban effluent (storm run-off, garages as well as drainage from paved and non-paved areas and from open fields within the Eldoret municipality. The three sites included upstream, midstream and downstream locations. In May 2020, during a period of moderate rainfall and no flooding, water samples were collected to accurately represented Sosiani River water rather than surface runoff. At each site, water samples were collected in clean, acid-washed polyethylene bottles with a capacity of 0.5 liters. Water was collected from about 20-30 cm below the water surface to avoid surface contaminants. A total of 15 samples were collected, with five samples obtained from each location. To ensure homogeneity of the water samples, each sample was shaken vigorously upon collection. The bottles were then sealed immediately to prevent contamination and stored in a cooler box with ice packs during transportation to the laboratory. In the laboratory, the water samples were stored at 4°C until further analysis. All samples were pretreated within 24 hours of collection to minimize changes in heavy metal concentrations.

Upon arrival at the laboratory, the water samples were allowed to reach room temperature before pretreatment. The samples were then filtered using Whatman No. 42 filter paper to remove suspended solids and particulates that could interfere with subsequent analyses. The filtrate was collected in clean glass beakers and set aside for analysis. To stabilize the heavy metals in the water samples and prevent precipitation, the pH of each sample was adjusted to below 2 by adding concentrated nitric acid (HNO_3). This acidification was essential to maintain the dissolved state of the metal ions during storage and analysis. After pH adjustment, the samples were transferred to clean, acid-washed polyethylene bottles and stored at 4°C until they were analyzed using Atomic Absorption Spectroscopy (AAS). For the batch adsorption experiments, aliquots of the pretreated water samples were taken, and their pH levels were adjusted to the desired values using 0.1 M sodium hydroxide (NaOH). The pH-adjusted samples were then used to evaluate the adsorption efficiency of the chemically treated *Cyanodon dactylon* adsorbents under varying conditions.

Preparation of stock solutions

Standard solutions of the selected heavy metals, including lead (Pb^{2+}), chromium (Cr^{6+}), cadmium (Cd^{2+}), and manganese (Mn^{2+}), were prepared to accurate calibrate the Atomic Absorption Spectroscopy (AAS) instrument. Stock solutions of 1000 mg/L concentration were obtained by dissolving the appropriate amounts of analytical grade lead nitrate ($Pb(NO_3)_2$), potassium dichromate ($K_2Cr_2O_7$), cadmium chloride ($CdCl_2$) and manganese sulfate ($MnSO_4{\cdot}H_2O$) in deionized water. From these stock solutions, a series of working standard solutions were prepared by serial dilution using deionized water of the 100ppm solution, creating concentrations of 2, 4, 6, 8, and 10 ppm for each metal ion. To maintain the pH at 4 and prevent metal ion precipitation, 0.5 M nitric acid or 0.5 M potassium hydroxide was added as needed. calibration.

Calibration of Atomic Absorption Spectroscopy (AAS)

The AAS was initially flushed with deionized water to establish a baseline reading. Then, each standard solution was aspirated into the instrument, starting from the lowest concentration to the highest. The absorbance readings were recorded for each concentration, and a calibration curve was generated by plotting absorbance against concentration.

To ensure the accuracy of the calibration, a linear regression analysis was performed on the calibration data, and the correlation coefficient (R^2) was calculated. R^2 quantifies the proportion of the variance in the dependent variable (absorbance) that is predictable from the independent variable (concentration of the heavy metals). R2 ranges from 0 to 1, where 1 indicates a perfect fit, meaning that all data points lie exactly on the regression line and 0 indicates no linear relationship between the concentration and absorbance. A high R^2 value (typically above 0.99) indicates that the calibration curve accurately represents the relationship between concentration and absorbance, ensuring reliable and precise quantification of the heavy metals in unknown samples. These calibration curves were subsequently used to determine the concentrations of metal ions in the water samples.

Batch Adsorption Experiments

The batch adsorption experiments were conducted in triplicates and were carried out in 250 mL Erlenmeyer flasks, where a fixed volume of water sample (100 mL) was mixed with a known amount of the untreated and treated *Cyanodon dactylon* adsorbent (1.0 g). The flasks were then placed on a mechanical shaker and agitated at a constant speed for a predetermined time, usually 100 minutes, to ensure thorough contact between the adsorbent and the metal ions in the water. The temperature was maintained at 25°C to mimic environmental conditions.

To study the impact of pH on adsorption efficiency, the experiments were repeated with water samples at different pH levels, ranging from 5, 7 and 9. To adjust the pH, either 0.1M HNO_3 or 0.1M NaOH was used. These pH values were chosen because they represent common environmental conditions and cover a range where heavy metal speciation and solubility significantly vary. At pH 5, the water is slightly acidic, where some metals might be more soluble and mobile. pH 7 is neutral, representing most natural water bodies, providing a baseline for comparison. pH 9 is slightly alkaline, where the solubility of some metals may decrease, promoting their adsorption. Each condition was tested in triplicate with 2 grams of untreated and chemically treated adsorbent. The average metal ion adsorption at each pH level was then calculated.

After the adsorption period, the mixtures were filtered using Whatman filter paper No. 42 to separate the adsorbent from the water. The filtrates were collected in clean glass containers for analysis. The residual concentrations of Pb^{2+}, Cr^{6+}, Cd^{2+} and Mn^{2+} in the filtrates were then determined using Atomic Absorption Spectroscopy (AAS). The absorbance readings from the AAS were compared to the calibration curves to quantify the remaining metal ion concentrations.

Calculation of adsorption efficiency

The percentage adsorption of each heavy metal ion was calculated using the following equation:

$$\% \, removal \, = 1 + \frac{(Co - Ce}{Co} * 100 \text{.........Eq 1}$$

Where;

C_O = Initial concentration of metal ions in the liquid phase

C_e = Concentration of metal ions in the liquid phase at equilibrium

Data analysis

Data was coded into SPSS version 20 and descriptive statistics was used to analyse the mean level of metal ions. Inferential statistics to compare means of metal ion concentrations and adsorption efficiencies across pH levels and sampling stations.

Results and Discussion

Mean levels of selected heavy metal ions in Sosiani River

Figure 2 presents the concentrations of selected heavy metals in water samples collected from Sosiani River, compared against the World Health Organization (WHO) recommended limits. The analysis focused on four heavy metals: Chromium (Cr^{6+}), Cadmium (Cd^{2+}), Lead (Pb^{2+}) and Manganese (Mn^{2+}).

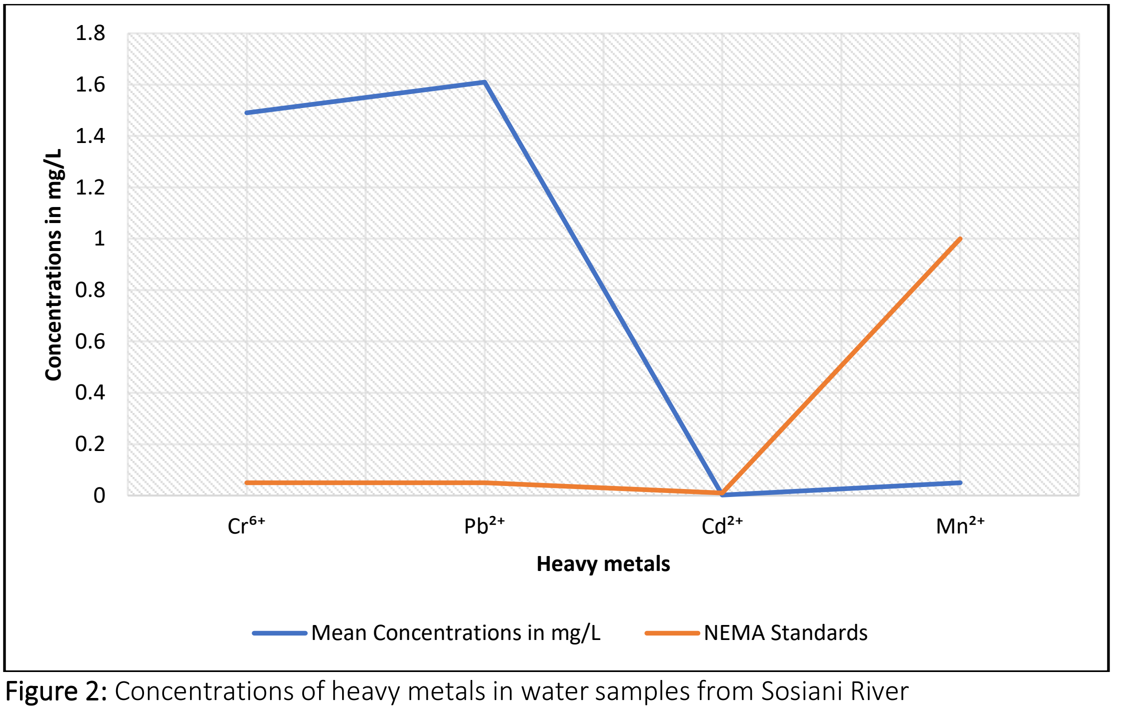

Figure 2: Concentrations of heavy metals in water samples from Sosiani River

Source: Author, 2023

The results indicate that the mean concentration of Chromium (Cr^{6+}) in the water samples was 1.49 mg/L, significantly exceeding the NEMA guideline of 0.05 mg/L (NEMA, 2023). Lead (Pb^{2+}) was also detected at a mean concentration of 1.61 mg/L, far surpassing the NEMA limit of 0.05 mg/L (NEMA, 2023). However, the concentration of Cadmium (Cd^{2+}) was found to be 0.002 mg/L, which is below the

NEMA recommended level of 0.01 mg/L (NEMA, 2023). Lastly, Manganese (Mn^{2+}) was recorded at a concentration of 0.05 mg/L, which is well within the NEMA guideline of 1.0 mg/L (NEMA, 2023). These findings suggest that the concentrations of Chromium and Lead in the Sosiani River significantly exceed safe levels, posing potential risks to the environment and public health. The elevated levels can be attributed to effluent discharged from sources such as industrial effluent, domestic sewerage, agricultural activities, wet textile processing and tanning activities. Several studies conducted in the area have reported similar concerns, Shieunda et al., (2019) who assessed the levels of heavy metals in water, sediments and fish in Sosiani River reported that high chromium levels were detected in water for 90% of the sites. On the other hand, Masakha et al. (2017) study on distribution of Selected Heavy Metals in Sosiani River in Eldoret, Kenya. Reported the mean levels increased midstream in town centre as more effluent was discharged into the river from various industries. This is attributed to use of Chromium in wood preservatives which are common in Eldoret town.

A similar finding was reported by Njuguna (2017) who while evaluating heavy metal levels in the water of the Nairobi River, Kenya. Reported that in three sites sampled chromium levels exceeding the WHO permissible limit for drinking water. The study attributed high levels to industrial effluent, domestic sewerage, agricultural activities, and solid waste were the main sources of pollution. This finding is concerning as elevated levels of Cr^{6+} in water are associated with various health risks, including cancer, kidney damage and skin irritation (WHO, 2017).

Munene et al. (2023) evaluated heavy metal concentration in surface water of Sosian river, Eldoret town, Uasin-Gishu County Kenya. The results disclosed that Pb concentrations were estimated to be in the range of 0.06 mg/l to 0.23 mg/l, higher than the permitted limit by WHO of 0.01 mg/l. Jepkoech et al. (2013) determined heavy metals in water and sediments and their bioconcentrations in plant (*Polygonum pulchrum*) in Sosiani River, Uasin Gishu County, Kenya and reported elevated levels of Pb (1.27 ± 0.17 ppm). Shieunda et al. (2019) conducted a study on levels of heavy metals in water, sediments and fish in Sosiani River and reported that lead values in water were above the NEMA and WHO thresholds of 0.01 mg/l.

The findings of this study are similar to those of Ochiba (2020) who reported in their study that Cadmium had levels below limits of detection of 0.001 mgl-1 in borehole water in Ongata Rongai, Kajiado County, Kenya. Shieunda et al. (2019) conducted analysis of spatial and temporal levels of heavy metals in water, sediments and fish in Sosiani River. The study reported that in the analysis of cadmium concentrations, it was observed that in wet season water had all 50% of the sites above the NEMA and WHO thresholds while all the sites were had values below the limits during the dry season. The findings of manganese were similar to those of Ochiba (2020) study who concluded that manganese levels were slightly higher in all water samples as compared to World Health Organization (WHO), Kenya Bureau of Standards (KEBS) and National Enrvironment Management Authority (NEMA).

Comparisons of heavy metals concentration across different locations

To assess whether there were significant differences in the concentration of heavy metals across various locations along the Sosiani River, a one-way ANOVA was performed. The results are summarized in Table 1.

Table 1: One-Way ANOVA results for heavy metals concentration across different locations of Sosiani River

	Df	F	P
Cr^{6+}	14	1.381	0.847
Cd^{+2}	14	1.395	0.034
Pb^{+2}	14	1.624	0.002
Mn^{+2}	14	0.969	0.009

Source: Author, 2023

The heavy metal concentrations in Sosiani River water samples varied significantly ($p<0.05$) across different locations. The ANOVA results for Cr^{6+} indicate a p-value of 0.847. Since the p-value is greater than 0.05, there is no statistically significant difference in Cr^{6+} concentrations across the different locations along the Sosiani River. The p-value for Cd^{+2} was 0.034. This p-value is below the 0.05 threshold, indicating a statistically significant difference in Cd^{+2} concentrations across the different sampling locations. For Pb^{+2}, the p-value was 0.002, which is well below the 0.05 significance level. This suggests that there are significant differences in Pb^{+2} concentrations across the various locations along the river. The ANOVA results for Mn^{+2} shows a p-value of 0.009. Similar to Cd^{+2} and Pb^{+2}, this p-value indicates a statistically significant difference in Mn^{+2} concentrations across the different locations. These findings highlight the uneven distribution of certain heavy metals in the river, which could be attributed to localized sources of contamination or varying environmental conditions.

The percentage adsorption of selected heavy metal ions from Sosiani river using untreated and chemically Treated *Cyanothon dactylon* grass

The study evaluated the percentage adsorption of heavy metal ions (Pb^{2+}, Cr^{6+}, Cd^{2+} and Mn^{2+}) from the Sosiani River using untreated and chemically treated *Cyanodon dactylon* grass. The findings are summarized in figure 3 below.

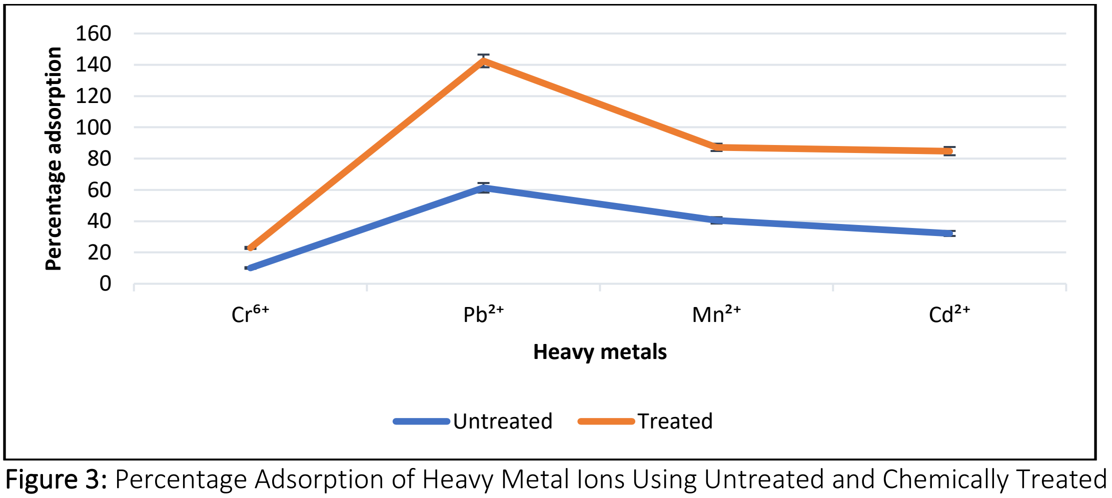

Figure 3: Percentage Adsorption of Heavy Metal Ions Using Untreated and Chemically Treated *Cyanodon dactylon* Grass
Source: Author, 2023

The results in figure 3 indicated that the chemically treated *Cyanodon dactylon* grass exhibited a higher percentage of adsorption across all tested heavy metals compared to the untreated *Cyanodon dactylon* grass. Specifically, Lead (Pb^{2+}) showed the highest increase in adsorption from 61.36% to 81.12%, followed by Cadmium (Cd^{2+}), which increased from 32.17% to 52.64%. Manganese (Mn^{2+}) and Chromium (Cr^{6+}) also showed improved adsorption after treatment, with Mn^{2+} increasing from 40.54% to 46.68% and Cr^{6+} from 10.1% to 12.83%. The findings indicated that the chemically treated *Cyanodon dactylon* grass exhibited a higher percentage of adsorption across all tested heavy metals compared to the untreated *Cyanodon dactylon* grass. This enhanced adsorption capacity was attributed to the chemical treatment process, which likely increased the availability of active sites on the grass's surface. The adsorbent capacity of metal ion removal varies, depending on the nature of the adsorbent, pH, contact time, particle size, and metal concentrations (Jain et al., 2016). Chai et al. (2021) conducted a review on conventional and novel materials towards heavy metal adsorption in wastewater treatment application and indicated that acid treatment often increases the surface area and porosity of the adsorbent, while alkali treatment can introduce negative charges on the surface, improving the material's affinity for positively charged metal ions.

Murage, (2022) conducted a study on adoption of selected heavy metals from water from River Ruiru, Kiambu County, Kenya using treated *Pennisetum purpureum* plant stalks. The study reported that modification of the adsorbent surface improved its adsorption capacity. The treated adsorbent achieved greater % adsorption in all the three metals. Ndimele and Jimoh (2011) performed research in Kenya that investigated the use of *Eichhornia crassipes* for the purpose of removing chromium (Cr) from wastewater that was produced by industrial processes. A high capacity to absorb and accumulate chromium in its tissues was revealed by the water hyacinth, which had removal efficiencies of up to 90% after being exposed to the element. According to the findings of the research, the broad root system of the plant is responsible for the plant's high adsorption capacity. This root system offers a huge surface area for the binding of metals.

Comparisons of heavy metals percentage adsorption using untreated and treated *Cyanodon dactylon* Grass

The study aimed to compare the percentage adsorption of heavy metal ions (Cr^{6+}, Cd^{2+}, Pb^{2+}, and Mn^{2+}) using untreated and chemically treated *Cyanodon dactylon* grass. A t-test was conducted to assess whether there were significant differences in the adsorption efficiency between the untreated and treated grass samples.

Table 2: T-Test results comparing heavy metals adsorption between untreated and treated *Cyanodon dactylon* Grass

Metals	T	Df	Significance (2-tailed)
Cr^{6+}	0.64	14	0.002
Cd^{+2}	0.43	14	0.030
Pb^{+2}	0.67	14	0.001
Mn^{+2}	0.22	14	0.027

Source: Author, 2023

The t-test results in table 2 comparing the percentage adsorption of heavy metals between untreated and treated *Cyanodon dactylon* grass reveal significant differences in the adsorption efficiency for all tested metals. The treated grass consistently outperformed the untreated grass in adsorbing heavy metal ions. The p values were 0.002, 0.030, 0.001 and 0.027 for Cr^{6+}, Cd^{2+}, Pb^{2+}, and Mn^{2+} respectively indicating a statistically significant difference in the adsorption of all the four metals between untreated and treated grass. These findings demonstrate that the chemically treated *Cyanodon dactylon* grass is significantly more effective in adsorbing heavy metals compared to the untreated grass.

Effect of pH variation on the percentage adsorption of selected heavy metals using untreated and chemically treated *Cyanodon dactylon* Grass

The table 3 presents the effect of pH variation on the percentage adsorption of selected heavy metals Cr^{6+}, Cd^{2+}, Pb^{2+}, and Mn^{2+}) using both untreated and chemically treated *Cyanodon dactylon* grass.

Table 1: Effect of pH Variation on heavy metal adsorption

Metals		Untreated	Treated
Cr	pH 5	21.46%	16.98%
	pH 7	10.1%	12.83%.
	pH 9	19.57%	38.64%
Cd^{+2}	pH 5	54.74%	37.64%
	pH 7	32.17%	52.64%
	pH 9	30.46%	49.78%
Pb^{+2}	pH 5	48.72%	32.19%
	pH 7	61.36%	81.12%,
	pH 9	26.90%	51.89%
Mn^{+2}	pH 5	76.54%	64.92%
	pH 7	40.54%	46.68%
	pH 9	56.92%	79.21%

Source: Author, 2023

The findings in table 3 illustrate that for Chromium (Cr^{6+}), the untreated grass had an adsorption efficiency of 21.46% at pH 5, which decreased to 10.10% at pH 7, but slightly increased to 19.57% at pH 9. The chemically treated grass, however, showed lower adsorption at pH 5 with 16.98%, increased to 12.83% at pH 7, and significantly improved to 38.64% at pH 9. For Cadmium (Cd^{2+}), the untreated grass exhibited higher adsorption at pH 5 with 54.74%, decreasing through pH 7 (32.17%) and pH 9 (30.46%). In contrast, the treated grass showed lower adsorption at pH 5 (37.64%) but higher efficiencies at pH 7 (52.64%) and pH 9 (49.78%). Lead (Pb^{2+}) adsorption was higher in untreated grass at pH 5 (48.72%) but decreased at pH 9 (26.90%), while the treated grass demonstrated lower adsorption at pH 5 (32.19%) and significantly higher efficiency at pH 7 (81.12%) and pH 9 (51.89%). For Manganese (Mn^{2+}), the untreated grass had the highest adsorption at pH 5 (76.54%), decreasing at pH 7 (40.54%) and slightly increasing at pH 9 (56.92%), whereas the treated grass showed lower adsorption at pH 5 (64.92%), with improvements at pH 7 (46.68%) and pH 9

(79.21%). These results suggest that chemically treated grass generally performs better at higher pH levels, while untreated grass tends to be more effective at lower pH levels, particularly for Mn^{2+}.

Comparisons of percentage of heavy metal adsorption among pH variations

The one-way ANOVA was performed to assess whether there are significant differences in the percentage adsorption of various heavy metals at different pH levels (pH 5, pH 7, and pH 9) for treated grass. The results of this analysis are presented in Table 4 below.

Table 4: One-Way ANOVA results for percentage of heavy metal adsorption in treated grass among pH 5, pH 7 and pH 9

	Df	F	P
Cr^{6+}	14	1.381	0.025
Cd^{+2}	14	1.395	0.045
Pb^{+2}	14	1.624	0.049
Mn^{+2}	14	0.969	0.001

Source: Author, 2023

The ANOVA results for Cr^{6+}indicate a p-value of 0.025. Since the p-value is less than 0.05, there is statistically significant difference in Cr^{6+} adsorption across the different pH levels. The p-value for cadmium was 0.045. This p-value is below the 0.05 threshold, indicating a statistically significant difference in Cd^{+2} adsorption across the different pH levels. For Lead, the p-value was 0.049, which is well below the 0.05 significance level. This suggests that there are significant differences in Pb^{+2} across the various pH levels. The ANOVA results for Mn^{+2} shows a p-value of 0.001 which indicated a statistically significant difference in Mn^{+2} adsorption across the different pH levels. These findings indicated that the percentage adsorption of all four heavy metals in treated grass significantly varies across different pH levels.

Table 5: One-Way ANOVA results for percentage of heavy metal adsorption in un treated grass among pH 5, pH 7 and pH 9

	Df	F	P
Cr^{6+}	14	1.126	0.001
Cd^{+2}	14	1.421	0.020
Pb^{+2}	14	1.317	0.032
Mn^{+2}	14	0.989	0.003

Source: Author, 2023

The one-way ANOVA results for the percentage of heavy metal adsorption in untreated grass across different pH levels (pH 5, pH 7, and pH 9) reveal significant differences for all metals examined. For Chromium (Cr^{6+}), the analysis yielded an F-value of 1.126 with a p-value of 0.001, indicating a statistically significant variation in adsorption across the pH levels. Cadmium (Cd^{2+}) showed an F-value of 1.421 and a p-value of 0.020, also suggesting significant differences in adsorption efficiency among the different pH levels. Similarly, Lead (Pb^{2+}) had an F-value of 1.317 with a p-value of 0.032, confirming significant variations. Manganese (Mn^{2+}) presented an F-value of 0.989 and a p-value of 0.003, further demonstrating significant differences in adsorption depending on the pH level. These results indicate that pH significantly affects the adsorption efficiency of untreated *Cyanodon dactylon* grass for these heavy metals.

Wan et al. (2014) conducted a study on the adsorption of Lead (Pb^{2+}) and Cadmium (Cd^{2+}) onto activated carbon derived from agricultural waste. The researchers found that the percentage adsorption of both metals increased with rising pH, reaching a maximum at around pH 5 to 6. Beyond this pH, the adsorption efficiency decreased slightly. This trend was attributed to the deprotonation of functional groups on the adsorbent surface at higher pH levels, which enhanced the electrostatic attraction between the negatively charged adsorbent surface and the positively charged metal ions. However, at very high pH levels, metal ions tend to precipitate as hydroxides, reducing the availability of free metal ions for adsorption. Similarly, Murithi et al. (2014) conducted a study on removal of cadmium (II) ions from water by adsorption using water hyacinth (*Eichhornia crassipes*) biomass. For initial Cd^{2+} concentrations of 10, 50, and 100 mg/L, the maximum percentage amounts adsorbed were 44.4, 13.1, and 4.9%, respectively. The maximum Cd^{2+} ion adsorption occurred at a pH of 6.0, and the least Cd^{2+} ion adsorption occurred at pH values less than 3.0 for all the initial concentrations studied. The adsorption capacity of *Eichhornia crassipes* increased with increasing pH and reached optimum capacity at pH 6.0. It can be assumed that as the solution pH increases, hydrolysis of the divalent metal ion, Cd^{2+}, takes place to form anionic hydroxide complexes that decrease the concentration of free metal ions and the affinity of the metal species for charged biosorbent sites. This decreases the metal sorption onto the biomass. Rao and Rao (2010) showed that at elevated pH levels, chemically treated *Moringa oleifera* seeds exhibited enhanced copper (Cu) adsorption capabilities. Sodium hydroxide (NaOH) treatment of the seeds increased the surface area and density of active sites for metal binding. At pH 8, the treated seeds exhibited a 60% increase in copper adsorption in comparison to the untreated seeds, which demonstrated superior performance in acidic environments (pH 4-6).

Conclusion

The analysis of heavy metal concentrations in Sosiani River water samples revealed concerning levels of contamination, particularly for Chromium (Cr^{6+}) and Lead (Pb^{2+}). The concentrations of Cr^{6+} and Pb^{2+} were significantly above the NEMA recommended limits, indicating substantial pollution that poses risks to both environmental and public health. In contrast, the levels of Cadmium (Cd^{2+}) and Manganese (Mn^{2+}) were within acceptable limits, suggesting that targeted remediation efforts are necessary to address the elevated levels of Cr^{6+} and Pb^{2+}.

Variations in heavy metal concentrations across different locations along the Sosiani River were noted, with significant differences observed for Cadmium, Lead, and Manganese. These variations imply that localized sources of contamination or differing environmental factors are influencing metal distributions. The uniform distribution of Chromium suggests a widespread source of pollution, while the varying concentrations of other metals highlight the need for more focused investigation into localized contamination sources.

The evaluation of *Cyanodon dactylon* grass for heavy metal adsorption revealed that chemical treatment significantly enhances its efficiency. Chemically treated grass demonstrated a higher capacity for adsorbing heavy metals compared to untreated grass. This suggests that chemical modifications can effectively improve the biosorbent's performance, making treated *Cyanodon dactylon* a viable and cost-effective option for water purification, particularly in areas affected by heavy metal pollution.

The impact of pH on the adsorption efficiency of *Cyanodon dactylon* grass was significant, with higher adsorption observed at lower pH levels. Untreated grass generally performed better at acidic conditions, whereas chemically treated grass showed reduced efficiency at lower pH. These findings emphasize the importance of optimizing pH conditions to enhance the performance of *Cyanodon dactylon* in heavy metal removal.

Recommendations

The study established that the Sosiani River was severely polluted with heavy metals, indicating a need for enhanced vigilance in the enforcement of environmental protection and waste management policies by relevant institutions, including the National Environmental Management Authority (NEMA). This was crucial to reduce the pollution in the river.

Public awareness and educational campaigns were needed to discourage the use of untreated Sosiani River water by communities living downstream.

Additionally, fishing activities and agricultural practices along the riverbanks were to be limited to prevent the consumption of fish and crops with high levels of heavy metal residues, thereby protecting local communities and the broader public.

Further research is recommended to assess the effectiveness of *Cynodon dactylon* in adsorbing other heavy metals and contaminants from polluted water. Also, there is need to also evaluate alternative methods of modifying or pre-treating *Cynodon dactylon* and their effects on the adsorbent's capacity.

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