Waste Water Treatment for Irrigation using Charred Biomass Residue

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ABSTRACT

Urban vegetable production in Ghana has engaged the exuberant youth in agriculture for its economic benefits. The impact of climate change coupled with erratic seasonal rainfalls has exacerbated crop failure due to water scarcity. Consequently, most urban farmers have resorted to the use of untreated wastewater for irrigation, especially in the dry season. Our study therefore aimed at treating municipal wastewater contaminated with heavy metals for vegetable irrigation. Two different charred biomass residues, biochar (BC) and activated carbon (AC), were used as adsorbents to remove heavy metals from wastewater. The two treatments consisted of 100 and 200 g of BC, and 100 and 200 g of AC, with one liter of untreated wastewater (WW) serving as the control. Heavy metals removed from the wastewater were Iron (Fe), Nickel (Ni), and Lead (Pb). Compared to the control, there were significant differences ($p \leq 0.05$) in Fe decontamination by the biochar and activated carbon in their respective rates, but comparing AC treatments to that of BC, there was no significant reduction of Fe concentrations after wastewater treatment. The adsorbents had no significant impact in reducing Ni in WW except for the 100 g AC that completely decontaminated Ni. Both BC and the AC had no impact on Pb decontamination from the wastewater. In general, activated carbon was desirable in decontaminating heavy metals from wastewater. However, the suitability of an adsorbent in decontaminating a given heavy metal from wastewater depends on the kind of heavy metal and the characteristic of the adsorbent used.

Keywords: heavy metals, biochar, activated carbon, wastewater, biomass residue, irrigation.

Introduction

Urban vegetable farming has increased relative to the increase in food demand by an ever-increasing global population. Vegetables were the third most-produced group of crops in the world at 1,127,927,000 tonnes and China ranked highest with 590,676,000 tonnes while Ghana produced 813,000 tonnes (FAO, 2021). However, the all-year-round production of vegetables is a challenge due to water scarcity, especially in the dry season (Yakubu et al., 2020). Rainfed agriculture has become unreliable due to the impact of climate change (Azari, Oliaye, & Nearing, 2021; Etwire, 2020; Mekonnen, Tessema, Ganewo, & Haile, 2021; Zhang, Liu, Zhang, Li, & Wang, 2021). Agricultural water management under irrigation system of farming would therefore play a beneficial role in conserving water for sustainable crop production. Even in the event of fluctuating rainfalls in the wet season, irrigation inevitably serves to supplement crop water requirement and minimizes crop failure; hence, a necessity for enhancing global food security. As of now, Ghana's land area equipped for irrigation has remained constant at 36,000 ha since 2014 (FAO, 2021).

In Ghana, vegetables thrive well in the savannah agro-ecological zones but production has been limited due to the long dry spell and the lack of irrigation resources in the area. Additionally, severe insect and pest infestation in the forest belts (wet zones) of the country has led to the constant application of agrochemicals on field-grown vegetables, raising consumers' concern about food contamination. Urban vegetable farming in Accra, Ghana has therefore attracted the youth in agriculture as it provides a lucrative and financial remuneration, especially in the dry season. However, the source of irrigation water for urban vegetable production is a challenge during the dry season, thus influencing the use of untreated wastewater from the drains in urban Accra (Obuobie et al., 2006).

According to FAO (2015), approximately 70 percent of the world's total freshwater is used for agricultural purposes. Because water safety regulations for irrigation in Ghana have not been exercised with stringent measures, some urban vegetable farmers have resorted to the use of untreated wastewater for irrigation. Yakubu et al. (2020) found the practice unhealthy and a threat to food safety as wastewater is a potential carrier of all forms of contaminants.

Wastewater could be defined as biological or physicochemical contaminated water with substances that have adverse effects on human health upon consumption. It is usually obtained from domestic, storm water runoff, municipal, and industrial effluent sources. More than 800 million farmers are engaged in urban agriculture and not less than 3.5 million ha of land is irrigated with wastewater globally (Qadir et al., 2010). It has also been observed that West African cities have less than 10% of the generated wastewater collected in piped sewage systems for treatment (Drechsel, Graefe, Sonou, & Cofie, 2006). Common contaminants in wastewater are heavy metals (also known as trace elements), coliforms (E. coli), and so on (Amoah, Drechsel, Abaidoo, & Henseler, 2007; Dai, Zhang, Xing, Cui, & Sun, 2019; Lente, Brimah, Atiemo, Studies, & Commission, 2014; Sorensen et al., 2014). Some heavy metals likely to be found in wastewater include arsenic (As), zinc (Zn), mercury (Hg), cadmium (Cd), chromium (Cr), manganese (Mn), iron (Fe), copper (Cu), magnesium (Mg) and lead (Pb). Wastewater can be treated for domestic, industrial, and irrigation purposes using treatment plants, filtration membranes, bioremediation, chemicals, and biomass residues among other technologies.

Treatment of wastewater for irrigation could enhance agricultural water management for sustainable vegetable production, but the cost of a particular treatment technology may influence the accessibility by smallholder vegetable producers in urban Accra. There are also limited research findings on the use of a cheap and accessible technology in treating wastewater for vegetable irrigation in Ghana.

Activated carbon, also called activated charcoal, is produced when carbonaceous materials are exposed to high temperatures to reduce their carbon content. The pyrolyzed material is further activated with either temperature or chemical to increase its pore spaces. Activated carbon is an advanced form of charcoal with diverse uses since ancient times (Çeçen, 2014). Biochar on the other hand is produced from the thermal decomposition of plant biomass in a partial or total absence of oxygen to produce char, carbon dioxide, and combustible gases intended specifically for application to soil (Sohi, Krull, Lopez-Capel, & Bol, 2010). In general, all carbon-rich substances increase in pore space when heated at high temperatures. It is these pore spaces that serve as a binding site for ion exchange during adsorption, chemisorption, and biosorption processes (Wijeyawardana et al., 2021). The difference between biochar and activated carbon is the activation process used in preparing activated carbon even though scientifically, they are both charred biomaterials. The most important characteristic of any carbonaceous material is its adsorption capacity (Kyzas and Kostoglou, 2014). The science of adsorption of elements to the surface of carbonized materials is the principle behind the use of activated carbon and biochar as adsorbents for heavy metals decontamination in our study.

The study, therefore, aimed at determining the efficacy of activated carbon and biochar's potential in ridding municipal wastewater of heavy metals for vegetable irrigation. The specific objectives were to (a) apply a simple and cost-effective technology in wastewater treatment using biomass residue (activated carbon and biochar), (b) vary the adsorbent amount to achieve corresponding levels of heavy metal decontamination, and (c) reduce the pollution potential of biomass residue by converting it into carbonaceous material for heavy metal adsorption. It was envisaged that both the amount of charred biomass residue and the surface area of the adsorption site would influence the degree of heavy metal decontamination from wastewater.

MATERIALS AND METHODS

Experimental site

Wastewater used for vegetable irrigation was sourced and sampled from Korle-Bu teaching hospital (KBTH) backyard gardens in Accra, Ghana. The site is located in the Accra Metropolis on Latitude 5°32’ 9.71” N and Longitude 0° 13’ 23.20” W along the Gulf of Guinea coastal belt in West Africa. Accra has a mean monthly temperature ranges from 24 °C to 28 °C and a bimodal rainfall pattern with an annual rainfall of 810 mm (Obuobie et al., 2006). There are two wet seasons, each lasting for three months. The major season start in April and ends in July while the minor rainy season span from September to November. The dry season usually starts in December and ends in March of the following year. The map in Figure 1 (Kufogbe, Forkuor, & Muquah, 2005) shows the major smallholder farms where wastewater was used for vegetable crop production in urban Accra.

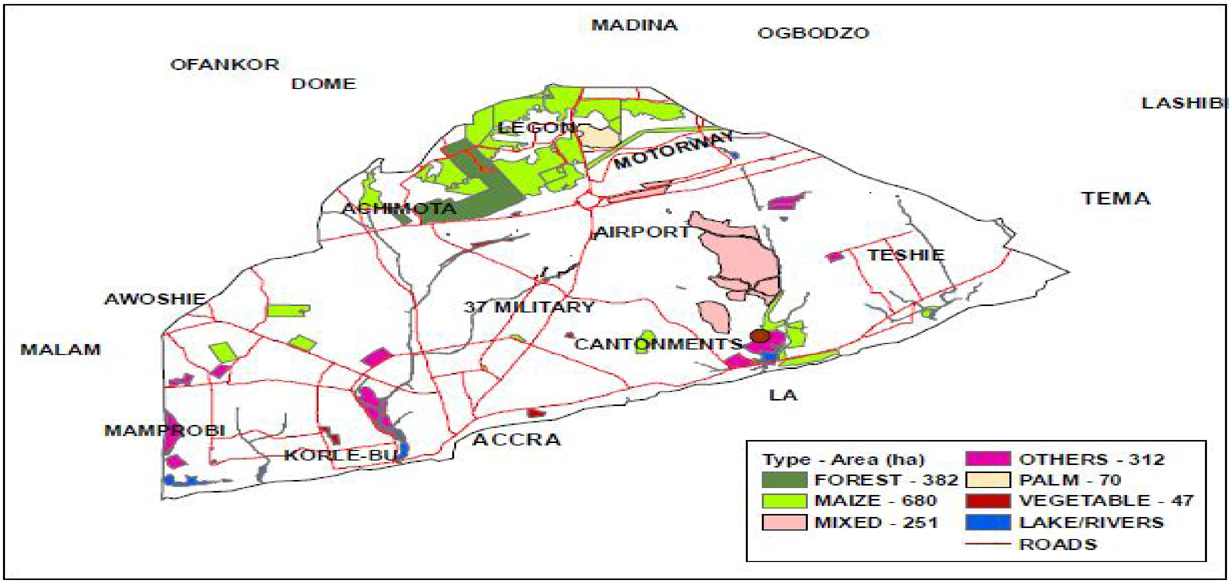

Figure 1: Small-holder vegetable sites in Greater Accra.

The experimental site under this study, KBTH backyard gardens where wastewater was used for vegetable irrigation, is highlighted green in Figure 2. The site currently covers less than 10 ha of land area. The present land size is prone to reduction for the hospital’s infrastructural development. The cultivated site is primarily used for vegetable farming throughout the year with some cereals (maize) cultivated in the wet seasons.

Figure 2: Map of Korle-Bu Teaching Hospital showing study area (highlighted green).

Experimental materials

Wastewater for irrigation

Irrigation water for vegetable production in the study area was sourced from open drains that carry wastewater from the hospital's departments and its staff residential facilities. Unlike the majority of farmers using hand watering cans and buckets, few of the farmers who were well-resourced used mechanized pumping machines to extract water from the dugout where wastewater was diverted for irrigation. Wastewater used for irrigation on the experimental site was sampled and transported to the Ecological Laboratory (ECOLAB) of the Institute for Environment and Sanitation Studies (IESS) of the University of Ghana in Legon to determine potential heavy metals composition. Precautionary measures in handling experimental water samples from the field to the laboratory for analysis were strictly adhered to avoid adulteration of the physicochemical properties of the sampled wastewater. It was kept in a refrigerator at 5 °C for 4 days in the laboratory while biochar and activated carbon were under preparation.

Biochar and activated carbon

Biochar and activated carbon constituted the charred biomass residue used in the filtration process to treat wastewater contaminated with heavy metals. Rice husk biochar was prepared at high pyrolysis temperature, above 500 °C using a locally manufactured kiln following the procedure below:

The kiln, produced from galvanized iron with air vent perforations around its circumference, was placed on the ground surface. Plant residue from pruned tree branches served as the heat energy source for powering the kiln. Dried rice husk was heaped around the erected kiln. The heat was transferred from the hot walls of the kiln to the heaped rice husk for charring. The heaped residue was frequently stirred and turned with a long hand shovel to ensure uniformly charred rice husk. After charring, water was used to quench and cool the rice husk biochar.

Activated carbon preparation, on the other hand, involved two processes, namely carbonization and activation (Buchel, Moretto, & Woditsch, 2000). Carbonization is the heat treatment or pyrolytic decomposition of rich-organic material such as wood or coal at a higher temperature range of 400 °C to 600 °C in partial or absence of oxygen (Bansal and Goya, 2005). Oxidative treatment is used in the activation process (Bansal and Goya, 2005; Marsh and Rodriguez-Reinoso, 2006). The procedure used in preparing activated carbon under the study is given below:

Charcoal produced from burnt plant residue after biochar preparation served as carbonized material for activated carbon preparation. The granular charcoal was crushed into smaller particle sizes and placed in a furnace for further heat treatment at 800 °C within hours. Carbon was combusted in the activation process as proposed by (B€uchel, Moretto, & Woditsch, 2000). Alternatively, chemical activation can be applied using K_2CO_3 and KOH to form activated carbon (Tay, Ucar, & Karagöz, 2009).

Both rice husk biochar and activated carbon were sieved to a particle size of 2 mm before application for wastewater treatment.

Experimental material characteristics

The effectiveness of an adsorbent (biochar or activated carbon) in treating wastewater of heavy metals depends on its surface area, pore space, carbon content, particle size, chemical constituent, and so on. Total dissolved solids (TDS), hydrogen ion concentration (pH), electrical conductivity (EC), and chemical elements (heavy metals constituent in adsorbent and wastewater) were determined. The TDS was determined from EC_w using a relation given by (Grattan, 2002) as in equation 1.

$$TDS = 640 * EC_w \qquad (1)$$

When $EC_w < 5$ mS/cm,

Where;

TDS is the total dissolved salts (mg/L),

640 is a conversion factor

EC_w is the electrical conductivity of water (mS/cm),

Values of EC_w and TDS determined were compared to United Nations (UN) Food and Agriculture Organisation (FAO) standards (Table 1) for irrigation water quality (Ayers & Westcot, 1985). The pH was also interpreted using FAO guidelines in Ayers and Westcot (1985).

Table 1: Guidelines for determining irrigation water quality

Quality challenge Salinity	Units	None	Degree of restriction Slight to moderate	Severe
EC_w	dS/m	< 0.7	0.7 - 3.0	> 3.0
TDS	mg/L	< 450	450 - 2000	> 2000

Results obtained under our study were interpreted using the designations "None, slight to moderate, and severe" as the degree of restriction for use in irrigation based on FAO guidelines for irrigation water quality (Ayers & Westcot, 1985).

Experimental treatment and design

Two treatment levels each for biochar and activated carbon were used in the study. Biochar treatment was 100 g (level 1) and 200 g (level 2) while the activated carbon treatment was also 100 g and 200 g respectively. One liter of untreated wastewater served as the control and it was combined with each level of the biochar and the activated carbon treatments in a filtration set up for heavy metal decontamination.

The first treatment combination consisted of 100 g biochar with one liter of wastewater. The second treatment combination was made up of 200 g of biochar with one liter of wastewater. The third treatment level consisted of 100 g activated carbon combined with one liter of wastewater. And the fourth treatment combination had 200 g activated carbon and one liter of wastewater. Treatment combinations and levels of AC and BC are presented in Table 2.

Table 2: Experimental material treatment combinations

	Adsorbent (charred biomass residue)			
	Biochar		Activated carbon	
Treatment amount (g)	100	200	100	200
Waste water amount / (L)	1	1	1	1
Treatment level	1	2	3	4

Note that each treatment level in the table was replicated three times.

our experiment where only adsorbent quantity was varied, Zahid et al. (2016) in a similar study varied both quantity and particle size of adsorbent in wastewater treatment. There were three replications for each treatment combination. Filtrates from each of the four treatment combination levels were collected and analyzed for concentrations of the given heavy metals. Results were then compared with the control to determine any difference in heavy metals concentrations.

Heavy metals in wastewater

Heavy metals are ubiquitous, and it is only through testing that the exact heavy metals and their concentration levels in any given sample can be revealed rather than by assumption. The suspected heavy metals to be removed under the study were zinc (Zn), iron (Fe), nickel (Ni), chromium (Cr), manganese (Mn), and lead (Pb). These trace elements were tested for in both adsorbent and wastewater before treatment. Treatment was carried out only when any of the above-given elements were tested and confirmed negative in the adsorbent but positive in the wastewater. Consequently, the six heavy metals proposed (Cr, Zn, Pb, Ni, Mn, and Fe) were initially tested in the experimental wastewater, biochar, and the activated carbon, and their concentrations were noted before treatment was done. Wastewater was tested for the presence of the selected heavy metals using the following procedure;

Wastewater in a corked bottle was shaken vigorously to unsettle any particles. A given volume, 100 ml, was sampled for digestion and 30 ml was filtered and sampled into three different measuring cylinders serving as three replicates. Those samples kept in the measuring cylinders were analyzed for the suspected heavy metals using atomic absorption spectrometry (AAS). All six heavy metals listed under the study were tested for in all three replicates. The particular heavy metals detected in the wastewater were proposed for decontamination using biochar and activated carbon based on the principle that the biochar and activated carbon were free from the respective heavy metals detected in the wastewater.

Heavy metal decontamination in wastewater

The proposed heavy metals that tested positive only in the wastewater were selected for removal using the biochar and activated carbon as adsorbents in a mechanical filtration system. The difference in concentration of each heavy metal in a filtrate and the control (unfiltered wastewater) was used to determine the percentage of heavy metal decontaminated from the wastewater. Filtration was done under the given biochar and activated carbon treatments in three replicates. In each case, the filtrate concentration was compared to the raw wastewater concentration for any given heavy metal to determine the percentage decontamination. Heavy metals decontamination using different treatments of biochar and activated carbon was carried out using the following procedure;

A known weight (W/g) of a given adsorbent (biochar or activated carbon), i.e. 100 and 200 g, each were measured and packed in corked plastic bottles with woven clot filters. One liter of the wastewater was measured and tested for the given heavy metal's initial concentration (C_i). Further, 1 L of the wastewater was poured in each of the 100 g and 200 g adsorbents packed in the corked plastic bottles in three replicates. The content was stored for infiltration and adsorption of heavy metals on the surface of the adsorbents to reach equilibrium in 24 hours. The cork of each plastic bottle was gently opened to collect filtrates after the 24-hour resident time. Filtrate (treated wastewater) from each adsorbent setup was sampled and tested for final concentrations (C_f) of the heavy metals using the AAS machine.

The amount of any given heavy metal adsorbed by the biochar and activated carbon in each case, i.e. adsorption capacity q_c (mg/g), was calculated using equation 2 given by Abdel-Ghani, El-Chaghaby, and Zahran (2015).

$$q_c = \frac{C_i - C_f}{W} * V \quad = \qquad (2)$$

Where;

q_c is the amount of heavy metal adsorbed [mg/g],

C_i is the concentration of heavy metal in wastewater before treatment [mg/L],

C_f is the concentration of heavy metal in wastewater after treatment [mg/L],

W is the weight of adsorbent (activated carbon or biochar) [g],

V is the volume of wastewater used [L].

Percentage of the heavy metals removed or decontaminated by the adsorbent, R, was also calculated using equation (3) (Abdel-Ghani, El-Chaghaby, & Zahran, 2015).

$$R = \frac{C_i - C_f}{C_i} * 100 \qquad (3)$$

Where;

R is the percentage of heavy metal adsorbed (%),

C_i is the concentration of heavy metal in wastewater before treatment [mg/L],

C_f is the concentration of heavy metal in wastewater after treatment [mg/L].

Statistical analysis

There were 15 water samples (untreated and treated wastewater) from all treatments analyzed for heavy metal composition. Data were processed in Microsoft excel and subjected to statistical analysis using GenStat (GenStat 12th edition). Analysis of Variance (ANOVA) was carried out to determine any significant difference in heavy metal adsorption by the different treatments of adsorbents using Duncan's least significance difference (LSD) test at $p < 0.05$.

RESULTS AND DISCUSSION

Physicochemical properties of experimental materials

Biochar, activated carbon, and sample wastewater, in general, have individual principal characteristics in terms of physicochemical properties. Regardless of the source, irrigation water contains some appreciable amounts of chemical elements alongside physical and biological constituents. The quality of irrigation water depends partly on these constituents but is measured against standards. Thus irrigation water quality is characterized by its biological, physical, and chemical constituents. The level of concentration of these constituents is the indicators of health concern when used in irrigating leafy vegetable crops. Other water characteristics such as color and odor are usually overlooked under an irrigation perspective. Chemical test involving the certification of heavy metals concentrations in the experimental wastewater as well as their proportions in the treated wastewater was compared to FAO standards and suitability indexed. Temperature (T), hydrogen ion concentration (pH), electrical conductivity (EC_w), and total dissolved solids (TDS) of each treatment is given in Table 3 and their suitability for irrigation was interpreted in Table 4 regarding the FAO standards. For instance, the result from our study recorded a pH range of 7.91 to 8.14 which was interpreted to be in the acceptable range for irrigation following the FAO guide (Ayers & Westcot, 1985) that reported a pH of 6.5-8.4 as an acceptable range for irrigation. Also, (Duncan, Carrow, & Huck, (2009) and Yermiyahu et al. (2009) proposed 7.9 - 8.14 as safe pH limits of irrigation water.

Table 3: Characteristics of waste water and filtrate after treatments

Treatment	pH	EC_w (mS/cm)	TDS (mg/L)	T (°C)
WW (1L)	8.14	1.14	729.6	29.8
100 g AC	8.10	1.24	793.6	29.4
100 g BC	8.06	2.38	1523.2	29.4
200 g AC	7.99	1.40	896.0	29.2
200 g BC	7.91	2.62	1678.8	29.6

Note: AC is activated carbon (g), BC is biochar (g) and WW is wastewater.

The carbonized materials herein given as biochar and activated carbon contain a high amount of potash (K_2O), i.e. source of potassium (K) when prepared under high pyrolysis temperature (Huggins et al., 2016). Compared to the untreated WW (control), filtrate from the adsorbents (BC and AC) recorded higher TDS and it was in the order 200 g BC > 100 g BC > 200 g AC > 100 g AC. The potassium (K) and the other elements such as Magnesium (Mg) from Magnesium oxide (MgO) content of carbonized materials are responsible for the increase in TDS in aqueous solutions. The trend in TDS means the rice straw biochar contained more potassium than the activated carbon. The increase in EC_w was directly proportional to TDS according to equation 1 and that was observed in the biochar and activated carbon filtrates as well (Table 3). Both the biochar and activated carbon contributed to reducing the initial wastewater pH but increased its electrical conductivity.

Quality of irrigation water based on FAO standards

The FAO irrigation water standards (Ayers & Westcot, 1985) provide the guideline for interpreting irrigation water quality based on the degree of restriction for use. The EC and TDS obtained under the study were interpreted based on the FAO standards (Table 4). It was observed that EC_w and TDS values recorded under all the treatments were categorized under 'slight to moderate' for use in irrigation. Hence both untreated and treated wastewater per the FAO standards were acceptable for irrigation considering their EC_w and TDS contents.

Table 4: Suitability of experimental water for irrigation

Treatment	Current study EC_w (dS/m)	Interpretation based on FAO standards	Current study TDS (mg/L)	Interpretation based on FAO standards
WW (1L)	1.14	Slight to moderate	729.6	Slight to moderate
100 g AC	1.24	Slight to moderate	793.6	Slight to moderate
100 g BC	2.38	Slight to moderate	1523.2	Slight to moderate
200 g AC	1.40	Slight to moderate	896.0	Slight to moderate
200 g BC	2.60	Slight to moderate	1678.8	Slight to moderate

Note that values of EC_w and TDS were interpreted based on FAO standards (Table 3).

Biochar and activated carbon effect on heavy metals removal from wastewater

Given the selected six heavy metals for adsorption, only Fe, Ni, and Pb were positive in wastewater but negative in the biochar and activated carbon. These three heavy metals were decontaminated in the untreated wastewater with different rates of biochar and activated carbon. Compared to the control (waste water) the concentration of each heavy metal reduced after treatment (Figure 3-6) with the biochar and activated carbon. In other words, when a lower concentration of a given heavy metal was recorded under any filtrate, it meant that part of the heavy metal had been retained by the adsorbent during filtration.

Treatment of wastewater for Fe decontamination showed a positive trend for the carbonaceous materials. It was observed that the concentration of Fe (0.6310 mg/L) in the wastewater (Figure 3) after treatment with activated carbon and biochar was generally reduced. There was a significant difference in Fe decontamination from the wastewater by the biochar and activated carbon in their various quantities. The activated carbon contributed to reducing Fe concentration more than the biochar in the wastewater (Figure 3). However, there was no significant difference in Fe decontamination among either the biochar or activated carbon treatments. Thus, comparing the 100 g to the 200 g AC, there was no significant difference in Fe decontamination and similar result was recorded for the 100 g and 200 g BC treatments.

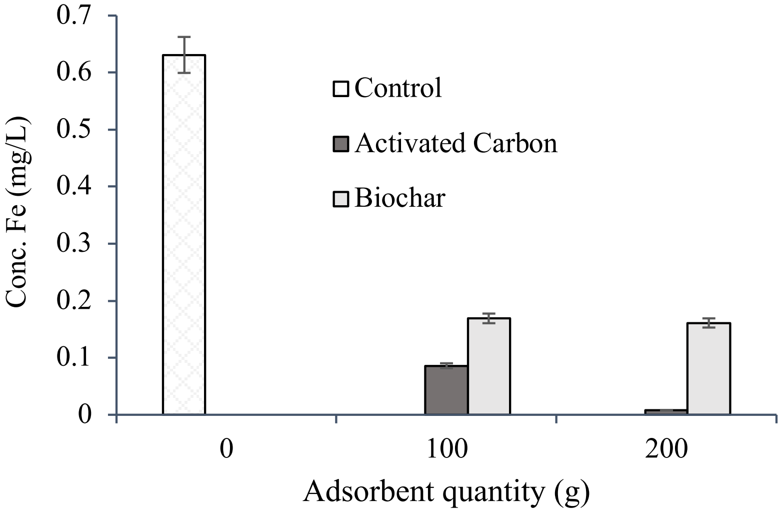

Figure 3: Removal of Fe from wastewater with biochar and activated carbon.

The second heavy metal decontaminated, Ni, with an initial concentration of 0.6737 mg/L in the wastewater also had its final concentration reduced in all the filtrates (treated wastewater). Apparently, the concentration of Ni after treatment of wastewater with 100 g AC was nil indicating its significant effect in decontaminating Ni completely from the wastewater. Unlike the Fe, there was no significant difference in Ni decontamination by the BC treatments when compared to the control (Figure 4). It was a clear indication that 100 g AC was more effective than a higher dosage of AC in treating wastewater contaminated with Ni. Wahi et al. (2009) reported similar results for total (100 %) removal of Lead and Mercury from aqueous solution at low adsorbent dosage.

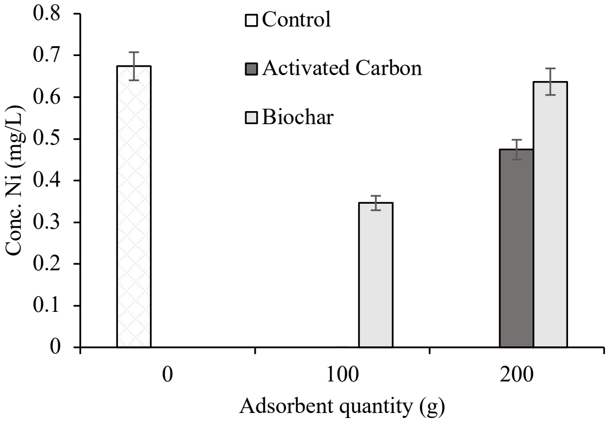

Figure 4: Removal of Ni from wastewater with biochar and activated carbon.

Finally, Pb concentration in the wastewater was appreciably reduced after filtering through the biochar and activated carbon treatments. In this case, the biochar for the first time, was observed to perform better in decontaminating Pb than the activated carbon. The 200 g biochar produced the best decontamination (Figure 5). Biochar was more effective in Pb decontamination as compared to the activated carbon though it could not eliminate the heavy metal (Pb) from the wastewater completely. As for the three heavy metals, there were significant reductions of their concentrations between the control, WW, and at least one of the other adsorbent treatments. But for the Pb, its concentration in the wastewater was not affected by any of the adsorbents. It was clear from the results that the given application rates of BC and the AC had no significant impact on Pb decontamination from the wastewater.

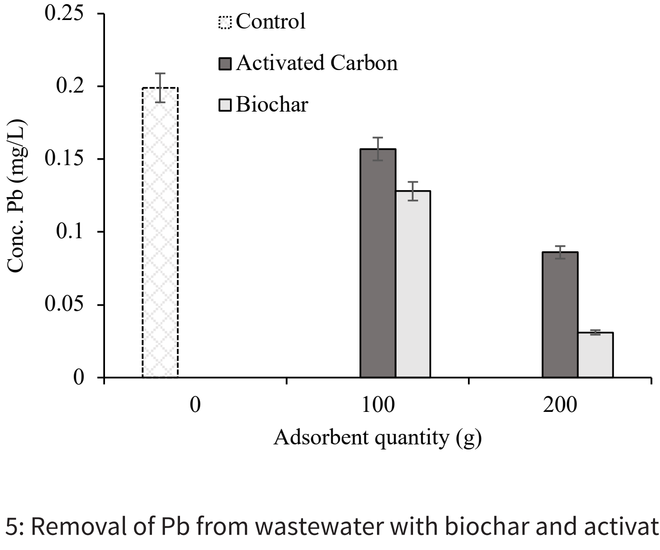

Figure 5: Removal of Pb from wastewater with biochar and activated carbon.

Effective wastewater treatment to eliminate heavy metals generally occurred during Iron (Fe) decontamination under the two different charred biomass residues used as adsorbents. The percentage of Fe eliminated from wastewater ranged from 73 to 99 % (Table 6). Comparing the efficacy of the two adsorbents in ridding wastewater of heavy metals, activated carbon dominated in adsorbing more Fe and Ni from wastewater after filtration. On the contrary, the trend in Pb decontamination was in favor of biochar even though insignificant. Both 100 and 200 g of the biochar treatments adsorbed more Pb than the corresponding activated carbon treatment. On that note, the suitability of an adsorbent removing a given heavy metal from wastewater will depend on the particular heavy metal and the type of charred biomass residue used as an adsorbent.

Adsorption capacity of biochar and activated carbon on heavy metals

Biochar and activated carbon adsorption of heavy metal and other organic substances have been reported in the literature (Lemley, Wagenet, & Kneen, 1995; Oleszczuk, Hale, & Lehmann, 2012; Sud, Mahajan, & Kaur, 2008). Under our study, the selected heavy metals in wastewater were not completely decontaminated except for the Ni in a 100 g activated carbon treatment. The number of heavy metals adsorbed (Table 5) by the biochar and activated carbon after wastewater treatment was calculated using equation 2.

Table 5: Amount of heavy metal decontaminated

Treatment	Fraction adsorbed, q (mg/g)		
	Fe	Ni	Pb
100 A	0.00546	0.00674	0.00042
100 B	0.00462	0.00328	0.00071
200 A	0.00311	0.00100	0.00056
200 B	0.00233	0.00018	0.00084

Note that the control (wastewater) treatment served as benchmark for measuring changes in heavy metal decontamination by the biochar and activated carbon.

Percentage adsorption of heavy metals by Activated carbon and biochar

Percentages of heavy metals adsorbed (Table 6) were calculated using equation 3. Nickel was the only element that was completely decontaminated in the 100 g activated carbon treatment. Percentage Fe decontaminated by the two different adsorbents was higher in the respective treatments as compared to the other heavy metals. In general, the amount of Fe decontaminated from the wastewater was more effective compared to the other heavy metals. The adsorption rate of Fe by the individual adsorbents was directly proportional to the amount of adsorbents used. A similar scenario of adsorption capacity of adsorbent was observed under Pb decontamination. Wahi et al. (2009) also reported a high level of mercury, lead, and copper removal from an aqueous solution by a correspondingly high amount of activated carbon produced from empty fruit bunch. On the contrary, the Ni adsorption rate by the two different adsorbents was inversely proportional to the amount of adsorbent used.

Table 6: Percentage concentration of heavy metals decontaminated

Treatment	Percentage heavy metal adsorbed, R (%)		
	Fe	Ni	Pb
100 AC	86.48	100	21.11
100 BC	73.17	48.60	35.68
200 AC	98.62	29.64	56.93
200 BC	73.96	5.44	84.57

AC and BC are activated carbon and biochar

Biochar and activated carbon have been reported to retain nutrients (Foereid, 2015). These nutrients are classified into macro and micronutrients which include some heavy metals. It has also been reported that the extent of nutrient retention is proportional to the amount of activated carbon and biochar used (Brantley, Brye, Savin, & Longer, 2015): a scenario also observed under our study but not in all cases. It was therefore evident from the study that biochar and the activated carbon adsorbed and retained the respective heavy metals during filtration.

CONCLUSIONS

Wastewater used for vegetable irrigation at the Korle–Bu Teaching Hospital backyard garden was treated to decontaminate heavy metals using biochar and activated carbon. A simple and affordable environmental-friendly technology involving the use of charred biomass residues was successful in decontaminating the heavy metals from wastewater. The extent of heavy metal decontaminated was highly influenced by the quantity of adsorbent in a direct proportional relationship except for Ni whose effective decontamination was inversely proportional to the quantity of AC. Compared to the biochar, activated carbon generally produced more favorable results in heavy metals decontamination. Nonetheless, converting both biomass residues into charred adsorbents contributed to minimizing the environmental pollution potential of the residues. Further research is therefore recommended to investigate the effect of different adsorbent quantities as well as a mixture of biochar and activated carbon on heavy metal removal from wastewater.

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