Potential health risk of using charcoal for water filtration

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ABSTRACT

This study determined the levels of selected heavy metals in activated charcoal and charcoals from different plants. Based on the assumption of complete transfer of the metals in charcoal to water which may occur through intake of water filtered with charcoal, the health risk of human exposure was estimated. The chemical analysis with atomic absorption spectrophotometry showed that the concentrations of the metals in the activated, bamboo, cassava and spinach charcoals were in the ranges of Zn: 24.89-684.21 mg/kg; Pb: 20.75-41.67 mg/kg; Ni: 0.00-85.33 mg/kg; Fe: 4427.98-10533.68 mg/kg; Cu: 26.84-1633.71 mg/kg; Cr: 55.34-333.34 mg/kg; and As: 18.71-112.68 mg/kg. The total concentration of the selected metals was highest in cassava charcoal (11479.52 mg/kg), then in activated charcoal (8141.68 mg/kg) and least in spinach charcoal (5010.41 mg/kg). The hazard quotient and hazard index values were less than one, indicating no non-carcinogenic risk due to these metals from intake of charcoal-filtered water. There was carcinogenic risk for ingestion of charcoal contaminated with Cr, As and Pb as the calculated values were higher than the acceptable limit (10^{-6}). These results suggested that the metal content in charcoal varied and the human exposure to some metals in charcoal-contaminated water through ingestion posed carcinogenic risk.

Key words: charcoal, concentration, metals, risk assessment, water.

INTRODUCTION

Due to natural and anthropogenic activities, there is massive introduction of pollutants in our environmental compartments, which deteriorate air, soil and water quality. Focusing on water, there are over one billion individuals drinking unsanitary water, and the medical implications resulting from the lack of this basic human right are horrific [1].

Conventional processes of water treatment include coagulation, sedimentation, filtration and disinfection. Some of the technologies for water purification are expensive and unavailable, especially to developing countries, hence researchers are identifying various affordable ways of getting clean water to meet the needs of the entire population. There are many types of water filters with the ability to remove some contaminants in water. Some of the common filters used in developing countries are ceramic filters, charcoal filters, plastic mesh micro-filters, sand filters and sediment filters.

Charcoal is a light, black, porous substance, consisting of mainly carbon and obtained as a residue in the partial burning of animal, vegetable, mineral substances and synthetic materials in which water and other volatile constituents are removed. Wood charcoal is obtained from plant materials while animal charcoal, is gotten on heating animal parts in the absence of oxygen. Activated charcoal is produced from charcoal and has well developed porous structure and large active surface area [2].Due to the porosity of charcoal, it has ability to readily absorb gases and liquids by chemisorption and physisorption processes. Charcoal is used in several adsorption experiments [3, 4]. Materials such as coconut shell and rice husk are carbonized to get charcoal, used in adsorptive separation and purification processes.

The numerous applications of charcoal and increasing awareness on the consequences of toxic metals have made it imperative for researches on the health implication of using charcoal.

In the use of charcoal for water filtration, water is forced through the carbon material and the contaminants are held in the gaps. These contaminants are toxic, taste and odour-producing compounds.

Many water companies and private homes in developed countries filter water using activated carbon filters [5].

Metals naturally occur in plants and animals. In the carbonization of materials, some metals will volatilize while others may be retained in the charcoal. Some of these metals are not biodegradable, potentially toxic and tend to accumulate when they enter living organisms [6, 7]. Numerous studies have been carried out on the potential health risk of heavy metals concentrations in several media such as fish [8], resuspended particles of urban street dust [9], water springs [10] and laundered shop towels [11].

In using charcoal for water purification, concern arises due the possibility of leaching of the toxic metals in the charcoal into the filtrate. Human exposure to the toxic metals may occur through drinking the water contaminated with the toxic metals, or through skin absorption of toxic metals while bathing with charcoal-filtered water.

This investigation determines the levels of toxic metals in charcoal from different plants. This would be helpful in estimating the potential health risk of possible exposure to the metals in charcoal via ingestion and skin contact with filtered water. This was on the assumption of complete transfer scenario of the metals in charcoal to water while using charcoal material in water filtration. Potential health risk of exposure to toxic metals in charcoal was assessed using hazard quotient, hazard index and carcinogenic risk criteria. Hazard quotient (HQ) criterion was used to assess non-carcinogenic risk of exposure to metals. HQ is a ratio of the average daily exposure dose (ADD) to the reference dose (RfD). The ADD was calculated from an equation using parameters such as the concentrations of the heavy metals in the charcoal. Obtaining a value that is less than one for HQ implied that there was no obvious non-carcinogenic risk while a value that is equal or greater than one meant that there was a risk. The cancer risks of some of the toxic metals were calculated by multiplying ADD with the slope factors.

In the present study, charcoals were produced from the wood in three types of plants (herb, shrub and tree) to ascertain the levels of selected toxic metals in the charcoals. A commercially available activated charcoal was also analysed for the toxic metals content.

The objectives of this study include:

1) to determine the levels of selected heavy metals (Fe, Cr, Zn, Pb, Cu, Ni, As) in activated charcoal and wood charcoals obtained from spinach, cassava and bamboo woods
2) to assess the potential health risk of human exposure to the heavy metals in the charcoals on intake of charcoal-contaminated water.

EXPERIMENTAL

Charcoal preparation from wood

Woods from spinach (herb), cassava (shrub) and bamboo (tree) were separately carbonised using the simple drum method [12]. The commercial activated charcoal (Cat. No. CL-12-0803) was obtained from Bio-Lab (Bio-Lab (UK) Limited, England). The samples were reduced to size and ground using a wooden mortar and pestle. The ground charcoal samples were sieved with a 250μm standard test sieve (Rupson Industries, India).

Charcoal preparation for metal analysis

About 0.5 g of each of the charcoals was separately subjected to acid digestion using aqua regia, cooled, filtered through No. 42. Whatman filter paper and the filtrate diluted to 50ml with deionized water. The concentrations of the metal were determined using atomic absorption spectrophotometry (AAS) Model AA-7000 (Shimadzu Corporation, Japan).

For quality assurance, triplicate digestions of the samples were analysed. Blanks were also analysed for the metal contents. Blanks, consisting of only the solvents chemicals for acid digestion, were run with the samples to check the interference, and minimize any errors due to losses during the digestion procedure**.**

Assessment of Exposure and Human health risk of toxic metals in charcoal

Health risk assessment classifies elements as carcinogenic or non-carcinogenic. The classification determines the procedure to be followed when potential risks are calculated [13]. In this study, the human health risk was characterized using hazard quotient, hazard index and carcinogenic risk index.

This study was based on the assumption of complete transfer scenario of the metals in charcoal to water while using charcoal material in water filtration. Potential exposure to the toxic metals in charcoals may occur through two major pathways, (a) ingestion/drinking of charcoal-filtered water and (b) dermal (skin) contact through bathing with charcoal-filtered water.

Determination of the Hazard Quotient

HQ is used to evaluate for non-cancer risk effects. It is the ratio of the average daily dose (ADD) (mg/kg/day) of the metal taken by a person to the reference dose (RfD) (mg/kg/day), which is an estimate of a daily exposure that is safe to human population [14].

$$HQ = \frac{\mathrm{ADD}}{\mathrm{RfD}} \quad (1)$$

HQ values were obtained for each element and for each exposure pathway.

Daily intake of a metal with drinking water was calculated using the following equation according to Batayneh [10].

$$\mathrm{ADD_{ingest}} = \frac{\mathrm{C\ x\ IR\ x\ EF\ x\ ED}}{\mathrm{BW\ x\ AT}} \mathrm{X}\ 10^{-6} \quad (2)$$

Where $\mathrm{ADD_{ingest}}$ is the average dose taken with drinking water, C is the concentration of the metal, IR is the ingestion rate (mean volume of water drank every day in liters). EF stands for exposure frequency and ED is the exposure duration. BW is the average body weight and AT is the averaging time.

Equation (3) [9] was used to calculate the daily dose of metal absorbed through dermal contact (ADD_{dermal}) (mg $kg^{-1}day^{-1}$) :

$$ADD_{dermal} = \frac{C \text{ x } SA \text{ x } SL \text{ x } ABS \text{ x } EF \text{ x } ED}{BW \text{ x } AT} X\ 10^{-6} \qquad (3)$$

Where ADD_{dermal} is the average daily dose of metal absorbed through dermal contact, *C* is the metal concentration (mg kg^{-1}), SA is the exposed skin area for adults, SL is the skin adherence factor, and ABS is the dermal absorption factor.

This study used recommended RfD for the metals [15, 16].

Determination of the Hazard Index (HI)

HI, which was developed by the US EPA, is used to estimate the risk to human health on exposure to more than one toxic metal [17].

The hazard index is the sum of the hazard quotients for all the determined toxic metals as expressed in equation [18].

$$HI = \sum HQ = HQ_{Fe} + HQ_{Ni} + HQ_{Cu} + HQ_{Zn} + HQ_{Cr} + HQ_{Pb} + HQ_{As} \qquad (4)$$

Determination of Carcinogenic Risk (CR) Index

Carcinogenic risk is the probability of an individual developing cancer from lifetime exposure to a potential carcinogen.CR was estimated using Equation (5) [17].

$$CR = ADD * SF \qquad (5)$$

where CR is carcinogenic risks and SF stands for Slope factor.

Some metals including As, Pb, Ni and Cr [9, 19] are known to be carcinogenic to humans.

Carcinogenic risk index was calculated for each of these metals using Equation (5).

RESULTS AND DISCUSSION

Heavy metal concentration

The levels of heavy metals in the charcoals are presented in Table 2. The concentration of Zn is highest in cassava charcoal (684.21mg/kg), followed by in spinach (354.05 mg/kg) and least with activated charcoal (24.89 mg/kg). Pb concentration is highest in activated charcoal (41.67 mg/kg) and least in spinach (20.75 mg/kg). The highest concentration of Ni was in bamboo (85.33 mg/kg) while cassava charcoal was not detected by the equipment. The concentration of Cr in charcoal was highest in activated charcoal (333.34 mg/kg) and least in spinach charcoal (55.34 mg/kg).Fe was the highest contributor to the metal concentration in each of the charcoals. Fe concentration in cassava is highest (10533.68 mg/kg) followed by that in activated charcoal (6004.89 mg/kg), with the concentration in spinach being the least (4427.98 mg/kg).The concentration of Cu in activated charcoal is 1633.71 mg/kg, 42.13 mg/kg in bamboo charcoal, 91.06 mg/kg in cassava charcoal and 26.84 mg/kg in spinach charcoal. Arsenic concentration was highest in spinach (112.68 mg/kg), then bamboo (112.68 mg/kg) and least with cassava charcoal (18.71 mg/kg).The total concentration of the selected heavy metals were in decreasing order cassava charcoal (11479.52 mg/kg)>activated charcoal (8141.68 mg/kg)>bamboo charcoal(6234.23 mg/kg)>spinach charcoal (5010.41 mg/kg).These metal concentrations obtained from the charcoals are influenced by human activities and environmental factors, which contribute to the availability of metals to plants that were converted into charcoals.

Human Health Risk Assessment

Levels of the selected metals in charcoals estimated to be leached into water and ingested or absorbed though skin contact (dermal route) are summarized in Table 3.

The average daily levels through ingestion (Add_{ingest}) and through dermal route (Add_{derma}) are given in Table 3.$Add_{ingest}$and Add_{derma} for Zn were in decreasing order: cassava>spinach>bamboo>activated charcoal. For Pb, the Add_{ingest} and Add_{derma} were in decreasing order: activated charcoal>cassava>bamboo>spinach. The Add_{ingest} and Add_{derma} for Ni were in decreasing order: activated charcoal>spinach>bamboo>cassava.The Fe, Cr and Cu in Add_{ingest} and Add_{derma} were in the same decreasing order of activated charcoal>cassava>bamboo>spinach. The Add_{ingest} and Add_{derma} for As were in decreasing order: Bamboo>spinach>activated>cassava.

The TheAdd$_{ingest}$ and Add$_{derma}$ of the metals are influenced by the amount in the charcoal. These results suggest that activated charcoal was the highest contributor for human exposure to Cr, Cu, Ni, and Pb. Cassava charcoal will expose human to more Fe and Zn, whereas human exposure to As will be most likely with the use of bamboo charcoal.

The levels of HQ_{ingest} and HQ$_{derma}$ for each of the selected metals was less than one (Table 3), which indicated that ingestion of charcoal-contaminated water through drinking or skin contact would have no significant risk of non-carcinogenic harmful effects on human health [20,21].

The Hazard index based on equation (4) was less than one, 5.64E-02 for HQ$_{ingest}$. Dermal RfD values for As and Fe were not available. According to Xu et al. [9], if HI < 1, there is no significant risk of non-carcinogenic effects and if HI > 1, there is a chance that non-carcinogenic effects may occur.

Carcinogenic Risk (CR) Assessment

The results on Table 4 shows the estimated cancer risk associated with the ingestion (CR$_{ingest}$) of toxic metals in water filtered using activated, cassava, bamboo and spinach charcoal.

The estimate of cancer risk due to Ni concentration was 8.06E-07 in activated charcoal, 3.11E-07 in bamboo charcoal and 4.62E-07 in spinach charcoal. These values indicate that Ni posed no cancer risk in the investigated charcoal. The estimate of cancer risk due to Cr was in the range of 1.00E-04 to 6.02E-04. These values did not fall within the cancer tolerable range of 10^{-6} to 10^{-4} [22]. The risk estimated for As were in the order of 1.20E-05 (cassava charcoal) to 7.28E-05 (bamboo and spinach charcoal). These values indicate cancer risk and therefore cause health risk concern.

In activated charcoal, the decreasing order of cancer risk due to metals are As>Cr>Ni. For Bamboo charcoal, the highest estimate of cancer risk was due to Cr, then Ni while the level of As posed minimal cancer risk compared to the other meals. The highest risk of cancer in cassava charcoal was due to As, then Cr, while Ni indicated no risk. Cr posed the highest cancer risk in spinach charcoal, while As posed the minimum cancer risk among the considered metals.

Overall, the CR$_{ingest}$ for Cr and As in the investigated charcoal were in the range of 10^{-6} to 8.06×10^{-5}, indicating the carcinogenic risks posed by ingestion of these metals. The acceptable or tolerable risk for regulatory purposes is in the range 10^{-6}–10^{-4} [23, 24].

A number of assumptions were made in the calculations of exposure. These are normal in studies of this nature [11].

CONCLUSIONS

This study confirmed that charcoal from different sources had different metal content. Assuming a complete transfer scenario of metals in charcoal to water during filtration, exposure to metals was higher through ingestion than through skin contact. Using hazard quotient criterion, human exposure to the metals through ingestion or skin contact posed non-carcinogenic risk. However, risk assessment showed that exposure to Cr, As and Pb through ingestion posed carcinogenic risk to human beings. A number of assumptions were made which may have overestimated or underestimated the risk posed by using charcoal to filter water.

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