



Mobility of Chromium, Copper and Arsenic in Amended Chromated Copper Arsenate Contaminated Soils

Caroline Kiwanuka Nakiguli^{1,2,3*}, Walter Ojok⁴, Timothy Omara^{2,3,5},
John Wasswa⁶ and Emmanuel Ntambi¹

¹Department of Chemistry, Faculty of Science, Mbarara University of Science and Technology, Mbarara, Uganda.

²Africa Centre of Excellence II in Phytochemicals, Textiles and Renewable Energy (ACE II PTRE), Moi University, Eldoret, Kenya.

³Department of Chemistry and Biochemistry, School of Sciences and Aerospace Studies, Moi University, Eldoret, Kenya.

⁴Department of Chemistry, Faculty of Science, Muni University, Arua, Uganda.

⁵Department of Quality Control and Quality Assurance, Agro Ways Uganda Limited, Jinja, Uganda.

⁶Department of Chemistry, Makerere University, Kampala, Uganda.

Authors' contributions

This work was carried out in collaboration among all authors. Authors CKN, WO, JW and EN designed the study. Author CKN performed analytical work. Authors CKN, WO and TO performed literature search. Authors CKN, TO and EN analyzed the collected data. Authors CKN and TO wrote the first draft of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJACR/2020/v6i430168

Editor(s):

(1) Dr. Angélica Machi Lazarin, State University of Maringá, Brazil.

Reviewers:

(1) Pranavkumar D. Bhangaonkar, Vadodara Institute of Engineering, India.

(2) Kaywood Elijah Leizou, Niger Delta University, Nigeria.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/61001>

Original Research Article

Received 02 July 2020
Accepted 09 September 2020
Published 23 September 2020

ABSTRACT

Aim: The use of copper-based preservatives such as chromated copper arsenate (CCA) and creosote to prolong the life of lumber present environmental concerns because they contain heavy metals and polycyclic aromatic hydrocarbons which are toxic to humans. The aim of this study was to investigate the effects of sewage sludge biosolid amendment on the distribution and mobility of chromium, copper and arsenic in chromated copper arsenate contaminated soils subjected to phytoremediation using maize (*Zea mays* L.).

*Corresponding author: Email: carolkiwanuka@gmail.com, cnakiguli@must.ac.ug;

Place and Duration of the Study: Random composite soil samples from Kitetika wood factory, Wakiso, Uganda and sewage sludge biosolid from National Water and Sewerage Corporation plant in Bugolobi, Kampala, Uganda were collected and prepared. Maize grains were obtained from FICA Seeds Limited (Uganda). The pot experiments and analysis of samples were done at Mbarara University of Science and Technology (Mbarara) and Directorate of Government Analytical Laboratory, Kampala (Uganda), respectively.

Methodology: The fresh CCA contaminated soils and sewage sludge biosolid were analyzed for physicochemical parameters and heavy metals (chromium, copper and arsenic). Sewage sludge biosolid was added to 1 kg of the contaminated soils at 5-25% (w/w) in 2 L plastic containers, watered and maintained at 25 °C for 14 days to stabilize. Controls were set up with unamended soils. Thereafter, maize was planted in the potted soils for 40 days. The concentrations of the trace metals in the soils were determined after 20 and 40 days of maize growth by atomic absorption spectroscopy.

Results: The concentrations of chromium, copper and arsenic in fresh CCA contaminated soils were 365.8 ± 6.18 mg/kg, 109.72 ± 14.04 mg/kg and 28.22 ± 3.8 mg/kg, respectively. Basing on mobility factor, bioavailability of the trace metals followed the chemical sequence copper (8.9%) < chromium (17.1%) < arsenic (30.2%).

Conclusion: The maize variety experimented could be used to phytoextract or phytostabilize the trace metals in the CCA contaminated soils without or with 5-25% amendment. Amendment with sewage sludge biosolid improved the phytoremediation potential of maize. Arsenic was the most mobile and bioavailable metal in CCA contaminated soils. Further studies should use other local maize varieties such as Longe series.

Keywords: Heavy metals; mobility factor; phytoremediation; sequential extraction; sewage sludge biosolid; Wakiso district.

1. INTRODUCTION

The dynamic nature of the building environment in Uganda poised by rapid surge in population, urban agriculture and massive industrialization has led to a rise in the demand for wood [1,2]. Thus, numerous unregulated industries have sprung up in Ugandan wood industry, leaving several environmental footprints [3-5]. Because of its susceptibility to attack by insects, wood is often preserved using chemicals [6,7]. Wood preservation have been classified broadly as oil borne or waterborne, contingent on the nature of the chemicals employed in the treatment formulation [7]. Oil borne preservatives include creosote and pentachlorophenol, which are used to treat wood for specific industrial uses. On the other hand, waterborne preservatives such as chromated copper arsenate (CCA) are the most common, and are used for preservation of lumber products used in commercial and residential applications [6].

The inadvertent use of preservatives such as CCA, creosote and other nascent copper-based formulations to prolong the life of lumber present environmental concerns because they contain heavy metals and polycyclic aromatic hydrocarbons which are toxic to humans [7-10]. Arsenical exposure in humans for example

causes vomiting, bloody diarrhoea, oesophageal discomfort, abdominal pain and in chronic cases may cause cancer and dermal changes [11]. Chronic human exposure to hexavalent chromium causes skin irritation and corrosion of mucous membranes of the respiratory system as well as lung cancer [12].

Previous reports prove that there is heavy metal pollution of environmental matrices in Uganda [13-17]. However, the toxicity, mobility, bioavailability and geochemical processes of trace metals in the environment vary, contingent on their geochemical fractions [18,19]. Sequential extraction is the preferred analytical technique for quantification of various binding fractions of heavy metals in environmental matrices [18,20]. Trace metals typically exists as water soluble, exchangeable, carbonates bound, occlude in manganese, iron oxides and hydroxides, bound to organic matter or appear in the residual fraction [21,22]. These forms are proportionate to the salient interaction processes, bioavailability, transfer behaviors as well as toxicity of the metals [23]. For example, wood treated with CCA contain arsenic in the inorganic pentavalent form [24,25] which act as an insecticide, and copper as Cu (II) which protects the wood from fungi [10]. Chromium on the other hand occurs in the trivalent form [26] and fixes

copper and arsenic complexes such as chromium (III) arsenate or chromium dimer-arsenic clusters [27] into the structures of lignin, cellulose or hemicellulose of the wood [28,29]. In soils however, the distribution of trace metals is influenced by pH, redox potential, ionic strength, biological, redox and complexation reactions.

The use of CCA for treatment of wood has been banned in many countries, though this has not been fully implemented in some developing countries like Uganda. In countries where it has been banned, some structures built using CCA treated wood are still in existence, and leach CCA into the immediate environment, causing heavy metal pollution [30,31]. For this reason, remediation of such contaminated soils are still required to reduce the risk of exposure to the heavy metals by humans. Phytoremediation, one of the popular approaches used for this purpose utilizes higher plants and their associated rhizosphere microorganisms to remediate soils, sediments, surface and ground water contaminated with toxic metals, organics and radionuclides by either removing the pollutants or lowering their bioavailability [32-34]. Plants effect this using their roots in which the pollutants are accumulated, and thus their bioavailability can be modulated [35,36]. In continuity of our study [5], we evaluated the effects of sewage sludge biosolid amendment on the potential of maize in cleaning up CCA contaminated soils. Further, the mobility of chromium, copper and arsenic in the

different fractions of the amended soils after 20 and 40 days of phytoremediation were investigated.

2. MATERIALS AND METHODS

2.1 Brief Description of the Study Area

The study was conducted using soil samples collected from Kitetika Wood Factory located along Gayaza road, Wakiso district of Uganda, about 7 miles from Metropolitan Kampala (coordinates 0.4030814 and 32.585174; Fig. 1). This establishment commenced active operations 20 years ago, producing treated poles used for distribution of hydroelectricity, fencing land and construction. The main chemical used for treatment of poles at this facility is CCA [5].

2.2 Sample Collection

Random aggregate soil samples (50 kg in total) were collected from Kitetika Wood Treatment Factory in Kitetika village, Nangabo Sub-county, Wakiso district of Uganda using plastic spades at depths of 0-15 cm. The composite samples were thoroughly mixed to give the final sample which was subsequently packed into air-tight polythene bags. Sewage sludge biosolid (50 kg) was obtained in clean polythene bags from National Water and Sewerage Corporation Plant situated in Bugolobi, Kampala, Uganda.

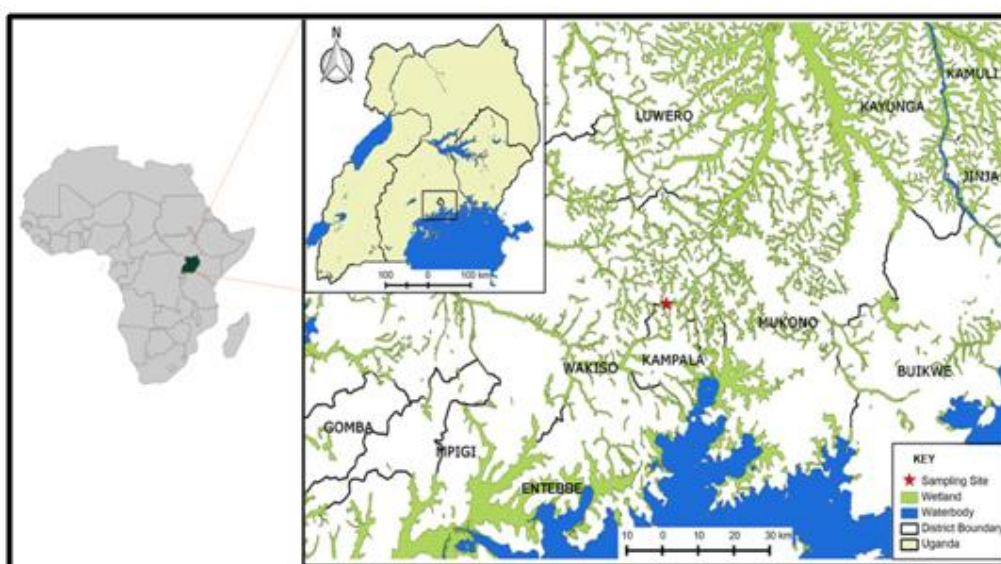


Fig. 1. Map showing the location of Uganda on the African continent and the sampling site (Kitetika Wood Factory) in Uganda (Adapted from Nakiguli et al. [5])

All the samples were transported to the Chemistry Laboratory of Mbarara University of Science and Technology, Mbarara, Uganda. Stones, plant tissues, pebbles and rock particles were removed from the samples which were allowed to dry at room temperature on clean polyethene sheets. The dried samples were subsequently ground and sieved through 2 mm stainless steel sieves, packed in air-tight plastic bags and stored at room temperature until commencement of analysis [5]. Maize grain (variety MM3) for this experiment were purchased from Farm Inputs Care Centre Limited (FICA Seeds Limited), Plot 40/41, Bombo road, Kawempe, Kampala (Uganda).

Both CCA contaminated soils and sewage sludge biosolid samples were subjected to physicochemical analysis for pH, nitrogen, organic matter, organic carbon, manganese, phosphorous, sand, clay, silt, cation exchange capacity (CEC) following previously used methods [5,37,38].

2.3 Sewage Sludge Application and Pot Experiments

Composted sewage sludge biosolid (SSB) were added to 1 kg of CCA contaminated soils at 5, 10, 15, 20 and 25% (w/w) and each was replicated thrice. The mixtures were potted in 2L plastic containers and these were watered with double distilled water to the soil water holding capacity (Fig. 2). Control soils were set up without any amendment. The containers were left at room temperature (25 °C) for two weeks for the soils to stabilize with intermittent mixing. After two weeks (14 days), soil samples (5 g) were obtained from each container and subjected to physicochemical analysis [5,37,38].

Maize grains were soaked in water for 5 hours and six viable ones were sown in each container. Watering was done with double distilled water when necessary and hand weeding was used to keep the plants free of weeds. The experiments were maintained in a screen house at 27-28 °C to preclude any aerial deposition of heavy metals on the soil surfaces. Soil samples were taken again from the potted soils after 20 and 40 days of maize growth.

2.4 Heavy Metal Analysis

Soil samples (1.00 g) were digested using 5 ml of a mixture of aqua regia (3:1 v/v concentrated

nitric acid: concentrated hydrochloric) and 1 ml of perchloric acid in 250 ml conical flasks. The samples were digested on a heating digester until white fumes of perchloric acid appeared. The solutions were cooled and subsequently filtered into 50 ml volumetric flasks and made to the mark with distilled water [18]. A 20% blank prepared using 15 ml of 63% nitric acid (Sigma Aldrich) and 5 ml of 98% sulphuric acid was first run to remove any traces of background interferences that would otherwise cause inaccuracy of results. All the samples were analyzed for Cr, Cu and As using AA 6300 Shimadzu double beam atomic absorption spectrophotometer (Shimadzu Corporation, Japan) at Directorate of Government Analytical Laboratory, Kampala, Uganda. Analyses, including five sets of standards for each metal were run in triplicate and the absorbances were used to compute the concentrations of the metals from the standard curves [39]. The results in mg/L from the instrument were converted to the standard unit (mg/kg) for easy comparison with the set international compliance guidelines [14,40].

All the reagents used in this study were of high analytical purity. All the volumetric ware used were soaked in 5% nitric acid overnight and rinsed with double distilled water. Standard solutions were prepared, and these were used for calibration and quality assurance for each of the analytical batch. Quality control was performed with spiked samples analyzed once for every 10 samples. Recovery percentages from the spiked samples ranged from 96.8% to 103%. Method detection limits with reagent blanks were calculated and these were 1.60, 0.50 and 0.90 mg/kg for Cr, Cu and As respectively. Analytical, equipment and filtration blanks were determined throughout the analyses, and subtractions were used to correct the heavy metal concentrations obtained. All samples were analyzed in triplicate.

2.5 Sequential Extraction and Assessment of Metal Mobility

The concentration of chromium, copper and arsenic in the soil fractions were determined after 20 and 40 days of planting. The extraction scheme used was based on six operationally defined fractions [41,42] modified from Tessier et al. [18] (Table 1).

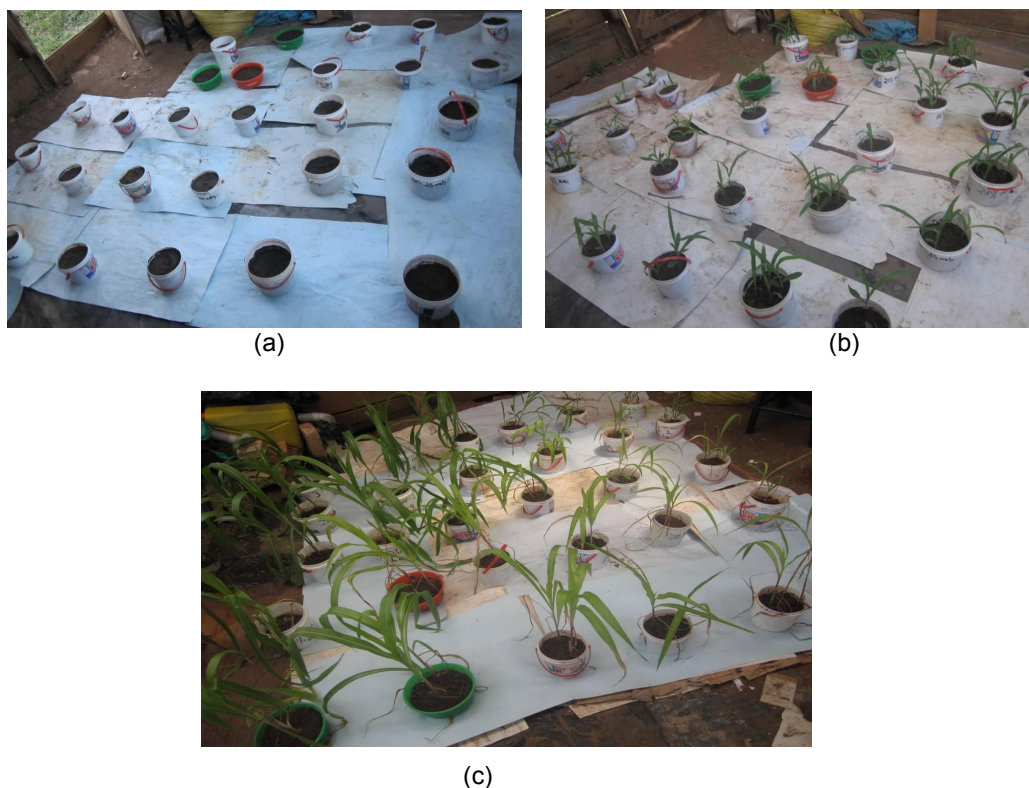


Fig. 2. Pot experiments: potted soils with amendments (a) before planting, (b) after germination of maize grain, (c) after 20 days of planting

Table 1. Six step sequential procedure for extraction of chromium, copper and arsenic in the soil samples

Fraction	Designation	Extraction procedure (for 1 g of dry sample)
F ₁	Soluble	Measured 20 ml of distilled water was added and shaken for 1 hour.
F ₂	Exchangeable	Measured 20 ml of 1M ammonium acetate was added to the residue from F ₁ . The pH of the resultant solution was adjusted to 7.0 with ammonium hydroxide solution and then agitated for 2 hours.
F ₃	Carbonate bound	Measured 20 ml of 1M ammonium acetate was added to the residue from F ₂ and the pH of the solution adjusted to 5.0 with concentrated acetic acid. The resultant mixture was agitated for 2 hours.
F ₄	Iron-manganese bound	Measured 20 ml of 0.04M ammonium acetate was added to the residue from F ₃ . This was incubated in a serological water bath at 60°C for 6 hours.
F ₅	Organically bound	The pH of 15 ml of 30% hydrogen peroxide solution in a conical flask was adjusted with concentrated nitric acid to 2.0. The acidic solution was added to the residue from F ₄ . The resultant solution was heated for 5.5 hours on a water bath at 80 °C. After cooling, 5 ml of 3.2M ammonium acetate in 20% nitric acid was added. The resultant solution was shaken for 30 minutes and diluted with 20 ml of double distilled water.
F ₆	Residual	Measured 5 ml of nitric acid and 1 ml of perchloric acid were added to the residue from F ₅ in a 250 ml conical flask. The mixture was heated on a hot plate at 60 °C for 6 hours. Exactly 1 ml of 2M nitric acid was added.

After each extraction, the supernatant solutions were separated by centrifugation at 1500 rotations per minute for 15 minutes (except for the residual fraction) followed by filtration through Whatman No. 1 filter paper. All the solid phases (residues) were washed with distilled water (10 ml) between the extraction steps. The washings were filtered through Whatman No.1 filter paper and the filtrate were added to the supernatant fraction.

Heavy metal mobility in the soils were assessed on the basis of their absolute and relative content of fractions weakly bound to the soil components. The relative index of the heavy metals mobility were calculated as the "mobility factor" using Equation 1 suggested by previous authors [41,43,44].

$$\text{Mobility factor} = \frac{F_1 + F_2 + F_3}{F_1 + F_2 + F_3 + F_4 + F_5 + F_6} \times 100 \quad (1)$$

Where F_1 to F_6 are the fractions defined in Table 1.

2.6 Statistical Analysis

All quantitative data, unless otherwise stated, were presented as means with errors represented by standard deviations attached. Significant differences between means of the investigated parameters were determined by one-way ANOVA and separated using Turkey pairwise test. The analyses were ran using Minitab statistical software (Release 17, Minitab Inc., USA) with statistical significance set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Characteristics of CCA Contaminated Soils and Sewage Sludge Biosolid

Physicochemical properties of soils influence metal speciation, mobility, bioavailability and toxicity in them. In this study, the pH of both CCA contaminated soils (6.77 ± 0.11) and SSB (6.64 ± 0.50) were near neutral (Table 2) and such pH enhances availability of cations for plant growth but these may not be phytotoxic [45]. Kim et al. [30], Tsetimi and Okieimen [46] recorded pH in the range of 5.90 ± 0.10 to 6.10 ± 0.20 and 5.92 ± 0.10 respectively for soils from CCA contaminated sites. The slight differences in the pH of CCA contaminated soils to those previously reported may be due to natural processes such as the rate of decomposition of organic matter and leaching of cations, and the

differences in their cation exchange capacities. Lower CEC of soils are known to lead to increase in soil pH [47]. Thus, the higher pH recorded could be due to soil factors as CCA is often applied as a water-based mixture of 0.6-6.0% (w/w) chromic acid, copper oxide and arsenic acid with pH between 1.6 to 2.5 [11].

The organic matter content of CCA contaminated soils and SSB were $4.40 \pm 0.08\%$ and $17.80 \pm 1.50\%$, respectively. Similarly, organic carbon recorded were $2.50 \pm 0.04\%$ for fresh CCA contaminated soils and $10.3 \pm 0.06\%$ for SSB. These significant differences ($P < 0.05$) are explained by the fact that SSB is a 50:50 mixture of organic and inorganic materials [45,48]. In this study, there was a significant difference ($P < 0.05$) in the CEC of CCA contaminated soils (6.80 ± 0.32 meq/100g) and that of SSB (14.70 ± 0.11 meq/100g). This could be due to the abundant cations in SSB than in the CCA contaminated soils. SSB had 166.90 ± 1.04 mg/kg of phosphorous which was higher than in CCA contaminated soils while the reverse was true for manganese. These could be due to the heterogenous nature of SSB compared to CCA contaminated soils. On the other hand, the soils had relatively higher percentage of sand (72%) and clay (19%) than SSB (51% and 15% respectively). Thus, the soils had a sandy-loam soil texture. Sandy soils depend heavily on the high CEC of organic matter for the retention of nutrients in the topsoil.

The heavy metal content of CCA contaminated soils were 365.80 ± 6.18 , 109.72 ± 14.04 and 28.22 ± 3.80 mg/kg for Cr, Cu and arsenic respectively. SSB had lower concentrations of the heavy metals. Interestingly, arsenic was below detection limit of 0.90 mg/kg in SSB. Higher concentrations of heavy metals in CCA contaminated soils are always expected because CCA used to treat lumber contain Cr, Cu and As [11]. The higher concentrations of trace metals in the soils than in SSB could have been due to initial leaching of the metals from treated wood [30,49-53]. There are three types of CCA (designated as A, B and C types) and the most popular is type C, chemically made up of about 47.5% CrO_3 , 18.5% CuO and 35.0% As_2O_5 [52]. The low concentration of arsenic recorded in CCA contaminated soils was previously reported elsewhere [46] but is not concordant with some preceding observations in which it recorded the highest concentration [30,54]. It was previously reiterated that although chromium in CCA contaminated matrices may be converted to the more toxic hexavalent form under the influence

of chemical oxidants, the amount of arsenic released is expected to be 30 to 40 times greater than the amount of hexavalent chromium released [55]. For this reason, arsenic should always remain the dominant element in terms of potential toxic impacts [55]. The levels of arsenic in the soils may have been lower than that of Cr and Cu because most of the original arsenic was fixed and then bound to the wood and/or may have undergone vertical and horizontal migration into the neighboring soils [31]. On the whole, the concentrations of Cr and Cu were above the maximum permissible guidelines of 200 mg/kg and 50 mg/kg, respectively while arsenic concentration was less than the 50 mg/kg maximum guideline permitted in agricultural soils [56,57].

3.2 Physicochemical Characteristics of the Unamended and Amended Soils

The properties of the potted control and CCA contaminated soils after 14 days of amendment with SSB are given in Table 3.

The amended soils recorded increment in nearly all the physicochemical parameters unlike the unamended soils. For example, pH first reduced to 6.35 ± 0.02 with 5% amendment and then increased up to 6.99 ± 0.18 at 25% amendment. Soil pH controls the solubility and hydrolysis of metal salts, ion pair formation, surface charge of manganese, iron and aluminum oxides, organic matter and clay [58] as well as metal uptake into plant roots which is usually metal specific [59]. There was increase in organic carbon from $2.55 \pm 0.01\%$ to a maximum of $8.65 \pm 0.03\%$ at 25% SSB amendment which may be due to the presence of compostable wastes generated within the soils [60]. Similarly, organic matter

increased from $2.50 \pm 0.04\%$ in the fresh soils to $16.43 \pm 2.05\%$ for 25% SSB amended soils. Amendment led to increase in organic matter probably due to the decomposition of organic supplied in the SSB to the soils. Similar observations were previously reported when poultry droppings were used for amendment of CCA contaminated soils [42]. Further, CEC was from 6.80 ± 0.32 meq/100g in the fresh soils to 18.96 ± 0.04 meq/100g for 25% SSB amended soils. CEC of soils varies according to the soil type, % clay, pH and organic matter [59], and since some of these parameters increased, CEC also increased. Increase in CEC is a favorable phenomenon in phytoremediation as it means reduced solubility of metals, keeping the plants active to perform perfect pollutant clean up [42]. Similarly, nitrogen and phosphorous content increased, probably due to the decomposition of the SSB used for amendment. However, manganese reduced significantly in both the control and amended soils. These could have been due to them being fixed into insoluble fractions of the soil.

3.3 Fractionation of Chromium, Copper and Arsenic in Unamended and Amended Soils 20 and 40 Days after Planting

Table 4 gives the bioavailability of chromium, copper and arsenic in different fractions of soils after 20 and 40 days of planting (DAP). In unamended CCA contaminated soils, chromium associated with soluble and iron-manganese oxide fractions were low. Most of it and copper were in the organic bound and residual fractions. Arsenic had the highest concentration in the exchangeable and residual fractions probably due to ion exchange. When exchanged for

Table 2. Physicochemical characteristics of fresh CCA contaminated soils and sewage sludge biosolid

Parameter	CCA contaminated soils	Sewage Sludge
pH	6.77 ± 0.11	6.64 ± 0.50
Organic matter (%)	4.40 ± 0.08	17.80 ± 0.26
Organic carbon (%)	2.50 ± 0.04	10.30 ± 0.06
CEC (meq/100g)	6.80 ± 0.32	14.70 ± 0.11
Nitrogen (%)	0.10 ± 0.01	0.32 ± 0.01
Phosphorous (mg/kg)	20.95 ± 0.17	166.90 ± 1.04
Manganese (mg/kg)	94.00 ± 0.61	68.80 ± 0.22
% Sand	72.00 ± 0.08	51.00 ± 0.06
% Clay	19.00 ± 0.33	15.00 ± 0.11
% Silt	9.00 ± 0.24	34.00 ± 0.51
Chromium (mg/kg)	365.80 ± 6.18	35.00 ± 1.06
Copper (mg/kg)	109.72 ± 14.04	1.00 ± 0.01
Arsenic (mg/kg)	28.22 ± 3.80	Below detection limit

another cation, arsenic is solubilized, becoming bioavailable for plant uptake. In the residual fraction, this could have been due to low pH. Soil parameters such as pH, organic matter, clay and iron oxides affect the redistribution of elements down the soil profile due to differences in their mobility. A low soil redox potential for example, increases mobility and toxicity of arsenic by reducing arsenic (V) to arsenic (III) [61].

With amendment, chromium concentrations increased but reduced with increase in the number of days. After 20 days, chromium that remained in the soil was more compared to that taken up by maize plants (Table 4). Chromium was low in the soluble and exchangeable fractions after 40 days compared to it was initially because it might have been adsorbed by the amendment. On the other hand, the concentration of copper was lowest in the soluble fraction with 25% amendment after 20 days while residual fraction had the highest concentration of copper. Normally, copper adsorption in the soil occurs in the most avid binding sites and the remainder is distributed among fractions bound with less energy, greater availability and mobility. Copper concentrations 40 DAP increased for all incremental amendments. As a cation, copper can be exchanged for other cations in clay and organic matter. Most copper deposited in the soil is strongly adsorbed to the upper soil layers and is bound to organic matter, carbonate minerals, iron and manganese oxides [61]. It may also get complexed by organic ligands such as carboxylic and phenolic groups,

or other organic acids, increasing its mobility in the soil [62].

After 20 and 40 days of planting, arsenic was strongly adsorbed in the exchangeable, organic, and residual fractions (Table 4). Adsorption and desorption of arsenic on oxides has been recognized as a mechanism of its mobility control [63-65]. In addition, carbon rich sludge is known to increase arsenic solubility [66]. As expected, phytoremediation had no significant impact on the concentration of arsenic in the soluble, exchangeable and carbonate fractions due to adsorption by organic matter. Previous authors [67,68] reported that addition of organic matter reduced arsenic mobility. Phosphate and arsenic compete directly for sorption sites on soil particles and about 77% displacement of total arsenic in the soil by phosphates was reported in a previous study [69]. Overall, these observations agreed with [42] who used poultry droppings as amendment and more metals were dissolved in the control pots than in pots with amendments.

3.4 Mobility of Chromium, Copper and Arsenic in Unamended and Amended CCA Contaminated Soils

Mobility of metals in soils is assessed basing on the absolute and relative content of the fractions weakly bound to the soil components. In this study, six operationally defined fractions (F₁ to F₆) representing the forms of the metals in the soils were used. The mean mobility factors were 17.1%, 8.9% and 30.2% respectively for chromium, copper and arsenic (Fig. 3).

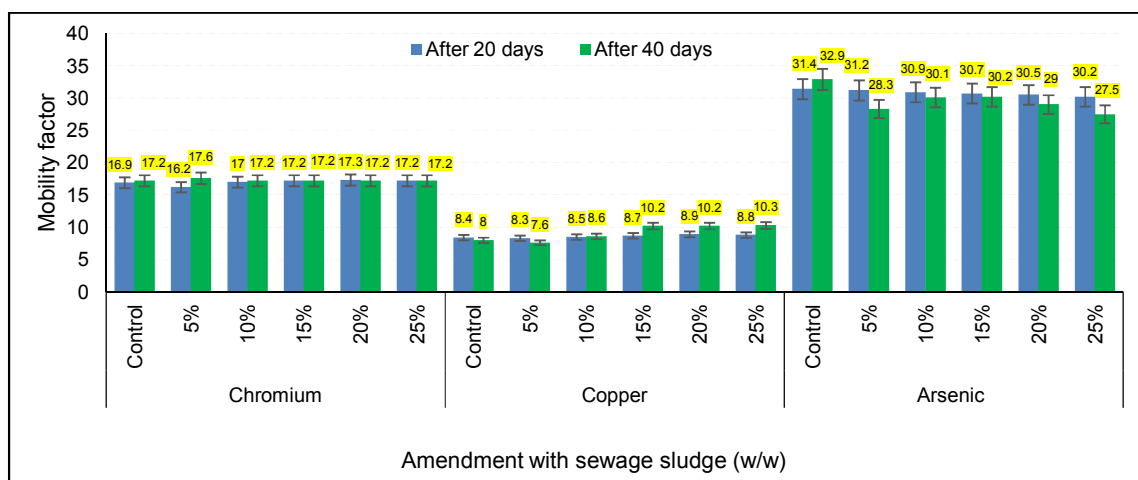


Fig. 3. Potential mobility of the heavy metals in chromated copper arsenate contaminated soils after 20 and 40 days of planting maize

Table 3. Characteristics of soils after 14 days amendment

Parameter	Control	5%	10%	15%	20%	25%
pH	6.12 ± 0.11	6.35 ± 0.02	6.67 ± 0.08	6.75 ± 0.08	6.77 ± 0.01	6.99 ± 0.18
Organic matter (%)	4.06 ± 0.13	9.69 ± 0.27	10.54 ± 0.11	14.84 ± 0.13	15.95 ± 0.32	16.43 ± 2.05
Organic carbon (%)	2.55 ± 0.01	4.84 ± 0.01	5.70 ± 0.01	6.77 ± 0.02	7.21 ± 0.01	8.60 ± 0.03
CEC (meq/100g)	8.34 ± 0.07	11.53 ± 0.05	15.70 ± 0.04	17.81 ± 0.07	18.84 ± 0.03	18.96 ± 0.04
Nitrogen (%)	0.11 ± 0.00	0.20 ± 0.01	0.27 ± 0.01	0.32 ± 0.003	0.44 ± 0.02	0.50 ± 0.01
Phosphorous (mg/kg)	22.99 ± 0.86	33.08 ± 2.88	54.13 ± 3.25	70.82 ± 2.36	74.27 ± 1.55	78.15 ± 1.68
Manganese (mg/kg)	7.47 ± 0.15	7.92 ± 0.08	8.14 ± 0.10	8.81 ± 0.09	9.81 ± 0.55	8.94 ± 0.04

Table 4. Concentration of trace metals in unamended and amended CCA contaminated soils 20 and 40 days after planting maize

Heavy metal	DAP	Fraction	Amendment with sewage sludge biosolid (w/w)					
			Control	5%	10%	15%	20%	25%
Chromium (mg/kg)	20	F ₁	9.39 ± 0.02	10.15 ± 0.09	10.51 ± 0.27	10.54 ± 0.19	10.91 ± 0.11	11.12 ± 0.14
		F ₂	14.42 ± 0.13	14.86 ± 0.03	15.79 ± 0.20	14.92 ± 0.38	14.97 ± 0.27	15.95 ± 0.15
		F ₃	13.37 ± 0.12	14.12 ± 0.03	14.64 ± 0.18	13.84 ± 0.36	13.88 ± 0.25	14.70 ± 0.14
		F ₄	7.49 ± 0.07	8.22 ± 0.01	8.20 ± 0.10	7.75 ± 0.20	7.77 ± 0.14	8.29 ± 0.08
		F ₅	32.52 ± 0.29	38.7 ± 0.07	35.61 ± 0.44	33.66 ± 0.87	33.76 ± 0.61	35.99 ± 0.33
		F ₆	142.84 ± 1.27	155.34 ± 0.27	156.00 ± 1.94	147.82 ± 3.81	148.26 ± 2.69	158.04 ± 1.46
	40	F ₁	9.35 ± 0.09	9.35 ± 0.02	9.39 ± 0.03	9.48 ± 0.04	9.50 ± 0.03	9.70 ± 0.02
		F ₂	13.27 ± 0.12	13.27 ± 0.03	13.33 ± 0.05	13.47 ± 0.06	13.5 ± 0.05	13.77 ± 0.03
		F ₃	12.31 ± 0.11	13.31 ± 0.03	12.36 ± 0.04	12.49 ± 0.05	12.51 ± 0.04	12.77 ± 0.03
		F ₄	6.89 ± 0.06	6.89 ± 0.01	6.92 ± 0.03	6.99 ± 0.03	7.01 ± 0.03	7.15 ± 0.01
		F ₅	29.94 ± 0.27	29.94 ± 0.06	30.06 ± 0.11	30.38 ± 0.13	30.44 ± 0.11	31.07 ± 0.06
		F ₆	131.49 ± 1.21	131.49 ± 0.28	132.04 ± 0.48	133.43 ± 0.55	133.70 ± 0.48	136.47 ± 0.28
Copper (mg/kg)	20	F ₁	0.78 ± 0.05	0.85 ± 0.06	1.05 ± 0.12	0.98 ± 0.13	1.09 ± 0.13	1.18 ± 0.11
		F ₂	2.62 ± 0.16	2.63 ± 0.17	3.01 ± 0.39	3.23 ± 0.37	3.35 ± 0.39	3.63 ± 0.34
		F ₃	3.47 ± 0.22	3.97 ± 0.51	3.97 ± 0.51	4.14 ± 0.25	4.26 ± 0.49	4.42 ± 0.45
		F ₄	8.54 ± 0.55	9.79 ± 1.26	10.37 ± 1.26	10.49 ± 0.62	10.90 ± 1.22	11.81 ± 1.12
		F ₅	10.25 ± 0.66	10.89 ± 0.65	11.75 ± 1.51	12.58 ± 0.51	13.08 ± 1.49	14.17 ± 1.34
		F ₆	57.70 ± 4.62	62.03 ± 9.81	64.96 ± 4.84	65.68 ± 11.02	65.93 ± 11.02	69.63 ± 10.69

Heavy metal	DAP	Fraction	Amendment with sewage sludge biosolid (w/w)					
			Control	5%	10%	15%	20%	25%
Arsenic (mg/kg)	40	F ₁	0.92 ± 0.11	0.73 ± 0.07	0.97 ± 0.12	1.26 ± 0.02	1.24 ± 0.02	1.27 ± 0.05
		F ₂	2.82 ± 0.35	2.24 ± 0.23	2.97 ± 0.36	3.82 ± 0.06	3.88 ± 0.66	3.92 ± 0.15
		F ₃	2.96 ± 0.30	3.72 ± 0.47	3.92 ± 0.47	5.03 ± 0.08	5.12 ± 0.08	5.17 ± 0.20
		F ₄	7.29 ± 0.73	9.17 ± 1.15	9.65 ± 1.17	12.40 ± 0.21	12.61 ± 0.21	12.75 ± 0.49
		F ₅	8.75 ± 0.88	11.00 ± 1.38	11.58 ± 1.40	14.88 ± 0.25	15.13 ± 0.25	15.30 ± 0.58
		F ₆	60.45 ± 10.07	61.65 ± 1.83	61.86 ± 4.27	61.99 ± 6.42	62.71 ± 0.25	64.82 ± 1.83
	20	F ₁	1.13 ± 0.01	1.14 ± 0.01	1.17 ± 0.11	1.19 ± 0.01	1.20 ± 0.02	1.24 ± 0.03
		F ₂	3.07 ± 0.01	3.18 ± 0.01	3.39 ± 0.03	3.54 ± 0.054	3.66 ± 0.13	3.95 ± 0.26
		F ₃	1.75 ± 0.01	1.77 ± 0.00	1.81 ± 0.01	1.84 ± 0.01	1.86 ± 0.02	1.92 ± 0.05
		F ₄	1.86 ± 0.01	1.88 ± 0.01	1.93 ± 0.01	1.96 ± 0.01	1.98 ± 0.03	2.04 ± 0.05
		F ₅	2.99 ± 0.02	3.03 ± 0.03	3.13 ± 0.01	3.19 ± 0.02	3.24 ± 0.06	3.37 ± 0.11
		F ₆	4.29 ± 0.11	4.34 ± 0.01	4.45 ± 0.01	4.52 ± 0.02	4.57 ± 0.06	4.71 ± 0.12
	40	F ₁	1.05 ± 0.02	1.06 ± 0.02	1.06 ± 0.01	1.07 ± 0.01	1.09 ± 0.04	1.12 ± 0.04
		F ₂	2.97 ± 0.06	3.01 ± 0.06	3.03 ± 0.05	3.04 ± 0.04	3.15 ± 0.14	3.25 ± 0.15
		F ₃	1.62 ± 0.02	1.63 ± 0.02	1.64 ± 0.02	1.65 ± 0.02	1.69 ± 0.06	1.73 ± 0.06
		F ₄	1.72 ± 0.03	1.74 ± 0.03	1.75 ± 0.02	1.75 ± 0.02	1.80 ± 0.06	1.84 ± 0.07
		F ₅	2.69 ± 0.06	2.72 ± 0.05	2.75 ± 0.05	2.75 ± 0.04	2.85 ± 0.13	2.95 ± 0.14
		F ₆	4.40 ± 0.13	5.47 ± 0.12	4.52 ± 0.10	4.54 ± 0.09	4.76 ± 0.30	4.98 ± 0.33

DAP: Days after planting

Metal forms in carbonate fractions are relatively less mobile and soluble than those in the exchangeable fraction. Hence, arsenic was potentially mobile and biologically available because of its high mobility factor. Chromium was relatively mobile whereas copper had a low mobility. The high mobility of arsenic is probably because it is present as anionic species such as H_2AsO_4^- or HAsO_4^{2-} under oxidized conditions [70,71]. Mobility of chromium depends on its oxidation state (+3 or +6), presence of organic matter and a divalent ion. Cr^{6+} which is more soluble, bioavailable and toxic [72] can readily be converted to oxides of Cr^{3+} or precipitated with iron hydroxides that have very low mobility and bioavailability in the soil [73]. For example, at a pH of 6.5-11.5, chromium exists as an immobile Cr^{3+} species such as $\text{Cr}(\text{OH})_3$ due to interaction with negatively charged ion colloids in the soil [73,74].

Comparatively, copper is readily retained in soil through non-specific adsorption mechanisms [75], specific adsorption mechanisms through soil surfaces, and formation of strong complexes with organic matter [76-79].

The average potential mobility of arsenic at different amendments varied significantly, indicating that it was more mobile than the other metals. The presence of heavy metals in this phase where they can be taken up by plants from the soils is the most hazardous to the ecosystem.

4. CONCLUSION

The MM3 maize variety experimented could be used to phytoextract or phytostabilize trace metals in the CCA contaminated soils without or with 5-25% sewage sludge amendment. Amendment with sewage sludge biosolid improved the phytoremediation potential of maize. Arsenic is more mobile and bioavailable in CCA contaminated soils than copper and chromium. The overall mobility of the trace metals considering their abundance in the fractions was exchangeable > bound to carbonate > bound to oxides > bound to organics > residual. Further studies should use other local maize varieties such as Longe series which take up to 120 days before maturity.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely

no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ETHICAL APPROVAL

This study was approved by the Chemistry Department, Mbarara University of Science and Technology, Uganda for Caroline Kiwanuka Nakiguli (Approval No. 2010/HD/019).

ACKNOWLEDGEMENTS

The authors are grateful to Deutscher Akademischer Austauschdienst (DAAD) and Mbarara University of Science and Technology for the scholarship and support given to CKN which gave birth to this communication. Sincere thanks to the management of Kitetika wood factory, National Water and Sewerage Corporation, FICA seeds limited, and directorate of government analytical laboratory (DGAL), Uganda for the resources and services generously accorded that made this research a success.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Turyahabwe N, Kakuru W, Asimwe M, Byakagaba P. Proximate and underlying causes of illegal timber trade in Uganda, precious forests-precious earth, miotrag zlati. IntechOpen. 2015;3-20. Available: <https://doi.org/10.5772/61014>
2. Josephat M. Deforestation in Uganda: Population increase, forests loss and climate change. Environ Risk Assess Remed. 2018;2(2):46-50. Available: <https://doi.org/10.4066/2529-8046.100040>
3. Walakira P, Okot-Okumu J. Impact of industrial effluents on water quality of streams in Nakawa-Ntinda, Uganda. J Appl Sci Environ Manage. 2011;15(2):289-296. Available: <https://doi.org/10.4314/JASEM.V15I2.68512>
4. Omara T, Othieno N, Obonge J, Ssebulime S, Kansime M. Characterization and

- prognostication of wastes generated by industries in Kampala industrial and business park-Namanve. OALib J. 2019; 6(1):e5189.
Available:https://doi.org/10.4236/oalib.1105189
5. Nakiguli CK, Namakula B, Odda J, Wasswa J, Ntambi E. Heavy metal accumulation in maize (*Zea mays* L.) grown on chromated copper arsenate (CCA) contaminated soil amended with treated composted sewage biosolid. J Environ Protect. 2018;9:1196-1204.
Available:https://doi.org/10.4236/jep.2018.911075
 6. Robey NM, Solo-Gabriele HM, Jones AS, Marini J, Townsend TG. Metals content of recycled construction and demolition wood before and after implementation of best management practices. Environ Pollut. 2018;242:1198-1205.
Available:https://doi.org/10.1016/j.envpol.2018.07.134
 7. Jones AS, Marini J, Solo-Gabriele HM, Robey NM, Townsend TG. Arsenic, copper, and chromium from treated wood products in the U.S. disposal sector. Waste Manage. 2019;87:731-740.
Available:https://doi.org/10.1016/j.wasman.2019.03.004
 8. Coles CA, Arisi JA, Organ M, Veinott GI. Leaching of chromium, copper, and arsenic from CCA-treated utility poles. Appl Environ Soil Sci. 2014;2014:11,Article ID 167971.
Available:https://doi.org/10.1155/2014/167971
 9. Oh J, Kim G. The effects of pH on copper leaching from wood treated with copper amine-based preservatives. Holzforschung. 2020;20190218.
Available:https://doi.org/10.1515/hf-2019-0218
 10. Kamchanawong S, Veerakajohnsak C. Arsenic, chromium, and copper leaching from CCA-treated wood and their potential impacts on landfill leachate in a tropical country. Environ Technol. 2010;31(4): 381-394.
Available:https://doi.org/10.1080/09593330903486657
 11. Saxe JK, Bowers TS, Reid KR. Arsenic in environmental forensics-contaminant specific guide, Academic Press. 1964;279-292.
 12. Katz SA, Salem H. Chemistry and toxicology of building timbers pressure-treated with chromated copper arsenate: A review. J Appl Toxicol. 2005;25(1):1-7.
Available:https://doi.org/10.1002/jat.1005
 13. Omara T, Karungi S, Kalukusu R, Nakabuye BV, Kagoya S, Musau B. Mercuric pollution of surface water, superficial sediments, Nile Tilapia (*Oreochromis nilotica* Linnaeus 1758 [Cichlidae]) and yams (*Dioscorea alata*) in auriferous areas of Namukombe stream, Syanyonja, Busia, Uganda. PeerJ. 2019; 7:e7919.
Available:http://doi.org/10.7717/peerj.7919
 14. Omara T, Ogwang R, Ndyamuhaki S, Kagoya S, Kigenyi E, Musau B, Adupa E. Spectroscopic analysis of selected priority trace metals in the extant East African gilled lungfish (*Protopterus amphibius*) in Lira municipal lagoon and its edibility health risk. Sci J Anal Chem. 2018;6(5):38-45.
Available:https://doi.org/10.11648/j.sjac.20180605.11
 15. Angiro C, Abila PP, Omara T. Effects of industrial effluents on the quality of water in Namanve stream, Kampala Industrial and Business Park, Uganda. BMC Res Notes. 2020;13(1):220.
Available:https://doi.org/10.1186/s13104-020-05061-x
 16. Ogwok P, Muyonga JH, Sserunjogi ML. Pesticide residues and heavy metals in Lake Victoria Nile perch, *Lates niloticus*, belly flap oil. Bulletin Environ Contam Toxicol. 2009;82(5):529-533.
Available:https://doi.org/10.1007/s00128-009-9668-x
 17. Birungi Z, Masola B, Zaranyika MF, Naigaga I, Marshall B. Active biomonitoring of trace heavy metals using fish (*Oreochromis niloticus*) as bioindicator species. The case of Nakivubo wetland along Lake Victoria. Physics Chem Earth. 2007;32(15-18):1350-58.
Available:https://doi.org/10.1016/j.pce.2007.07.034
 18. Tessier A, Campbell PGC, Bisson M. Sequential extraction procedures for the speciation of particulate trace metals. Anal Chem. 1979;51(7):844-851.
Available:https://doi.org/10.1021/ac50043a017
 19. Miaomiao H, Wenhong L, Xinqiang L, Donglei W, Guangming T. Effect of composting process on phytotoxicity and speciation of copper, zinc and lead in sewage sludge and swine

- manure. *Waste Manage.* 2009;29(2):590-597.
Available: <https://doi.org/10.1016/j.wasman.2008.07.005>
20. Tsai LJ, Yu KC, Chang JS, Ho ST. Fractionation of heavy metals in sediment cores from Eil-Pen river, Taiwan. *Water Sci Technol.* 1998;37(6-7):217-224.
Available: [http://dx.doi.org/10.1016/S0273-1223\(98\)00201-7](http://dx.doi.org/10.1016/S0273-1223(98)00201-7)
 21. Suanon F, Sun Q, Mama D, Li J, Dimon B, Yu CP. Effect of nanoscale zerovalent iron and magnetite (Fe₃O₄) on the fate of metals during anaerobic digestion of sludge. *Water Res.* 2016;88:897-903.
Available: <https://doi.org/10.1016/j.watres.2015.11.014>
 22. Zhang M, Yang C, Jing Y, Li J. Effect of energy grass on methane production and heavy metal fractionation during anaerobic digestion of sewage sludge. *Waste Manage.* 2016;58:316-323.
Available: <https://doi.org/10.1016/j.wasman.2016.09.040>
 23. Najamuddin PT, Sanusi HS, Nurjaya IW. Seasonal distribution and geochemical fractionation of heavy metals from surface sediment in a tropical estuary of Jeneberang River, Indonesia. *Mar Pollut Bull.* 2016;111(1-2):456-462.
Available: <https://doi.org/10.1016/j.marpolbul.2016.06.106>
 24. Khan BI, Jambeck J, Solo-Gabriele HM, Townsend TG, Cai Y. Release of arsenic to the environment from CCA-treated wood. 2. Leaching and speciation during disposal. *Environ Sci Technol.* 2006;40(3):994-999.
Available: <https://doi.org/10.1021/es051471u>
 25. Khan BI, Solo-Gabriele HM, Townsend TG, Cai Y. Release of arsenic to the environment from CCA-treated wood. 1. Leaching and speciation during service. *Environ Sci Technol.* 2006;40(3):988-993.
Available: <https://doi.org/10.1021/es0514702>
 26. Song J, Dubey B, Jang Y, Townsend TG, Solo-Gabriele HM. Implication of chromium speciation on disposal of discarded CCA-treated wood. *J Hazard Mat.* 2006;128(2-3):280-288.
Available: <https://doi.org/10.1016/j.jhazmat.2005.08.004>
 27. Nico PS, Fendorf SE, Lowney YW, Holm SE, Ruby MV. Chemical structure of arsenic and chromium in CCA-treated wood: Implications of environmental weathering. *Environ Sci Technol.* 2004;38(19):5253-5260.
Available: <https://doi.org/10.1021/es0351342>
 28. Vera VP, Cuevas UE, Cortes A. Optimization of a quality model for CCA industrial impregnation of Pinus radiata D. Don agricultural fencing stakes. *Wood Res.* 2013;58(1):131-140.
Available: <http://www.woodresearch.sk/wr/201301/14.pdf>
 29. Dawson BSW, Parker GF, Cowan FJ, Hong SO. Interlaboratory determination of copper, chromium, and arsenic in timber treated with preservative. *Analyst.* 1991;116(4):339-346.
Available: <https://doi.org/10.1039/AN9911600339>
 30. Kim H, Kim DJ, Koo JH, Park JG, Jang YC. Distribution and mobility of chromium, copper, and arsenic in soils collected near CCA-treated wood structures in Korea. *Sci Total Environ.* 2007;374(2-3):273-281.
Available: <https://doi.org/10.1016/j.scitotenv.2006.12.047>
 31. Usman ARA, Lee SS, Awad YM, Lim KJ, Yang JE, Ok YS. Soil pollution assessment and identification of hyperaccumulating plants in chromated copper arsenate (CCA) contaminated sites, Korea. *Chemosphere.* 2012;87(8):872-878.
Available: <https://doi.org/10.1016/j.chemosphere.2012.01.028>
 32. Omara T, Adupa E, Laker F, Kalukusu R, Owori T. Potential of *Sorghum bicolor* L. (Moench) and the Effectiveness of Some Organic Amendments in Remediation of Petroleum Oil-Vitiated Soils of an Automobile Repair Workshop in Urbanite Kampala. *Asian J Appl Chem Res.* 2019;3(1):1-10.
Available: <https://doi.org/10.9734/ajacr/2019/v3i130085>
 33. Li C, Yu F, Li Y, Niu W, Li J, Yang J, Liu K. Comparative analysis of the seed germination of pakchoi and its phytoremediation efficacy combined with chemical amendment in four polluted soils. *Int J Phytoremed;* 2020.
Available: <https://doi.org/10.1080/15226514.2020.1741508>
 34. Yan A, Wang Y, Tan SN, Yusof LMN, Ghosh S, Chen Z. Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. *Front Plant Sci.* 2020;11:359.

- Available:<https://doi.org/10.3389/fpls.2020.00359>
35. Ali H, Khan E, Sajad MA. Phyto-remediation of heavy metals-concepts and applications. *Chemosphere*. 2013;91:869-881.
Available:<https://doi.org/10.1016/j.chemosphere.2013.01.075>
 36. Jacob JM, Karthik C, Saratale RG, Kumar SS, Prabakar D, Kadirvelu K, et al. Biological approaches to tackle heavy metal pollution: a survey of literature. *J Environ Manage*. 2018;217:56-70.
Available:<https://doi.org/10.1016/j.jenvman.2018.03.077>
 37. Okalebo JR, Gathua KW, Woomer PL. Laboratory methods of soil and plant analyst working manual unpublished report 2nd edition RSBF-CIAT and Sacred Africa Nairobi, Kenya. 2002;131.
Available:<https://www.coursehero.com/file/39940638/SoilAnalysesmanualpdf/>
 38. Page AL, Miller RH, Keeney DR. Ed 2 Part II. *Methods of soil analysis*. Madison, WI American Society of Agronomy. 1982; 803.
 39. Omara T, Nteziyaremye P, Akaganyira S, Opio DW, Karanja LN, Nyangena DM et al. Physicochemical quality of water and health risks associated with consumption of African lung fish (*Protopterus annectens*) from Nyabarongo and Nyabugogo rivers, Rwanda. *BMC Res Notes*. 2020;13(1):66.
Available:<https://doi.org/10.1186/s13104-020-4939-z>
 40. Nteziyaremye P, Omara T. Bioaccumulation of priority trace metals in edible muscles of West African lungfish (*Protopterus annectens* Owen, 1839) from Nyabarongo River, Rwanda. *Cogent Environ Sci*. 2020;6(1):1779557.
Available:<https://doi.org/10.1080/23311843.2020.1779557>
 41. Salbu BTK, Oughton DH. Characteristic of radioactive particles in the environment. *Analyst*. 1998;123(5):843-849.
Available:<https://doi.org/10.1039/A800314I>
 42. Ikhuoria EU, Urunmatsoma SOP, Okieimen FE. Preliminary investigation of chemical fractionation and heavy metal accumulation in plant maize (*Zea mays*) grown on chromated copper arsenate contaminated soil amended with poultry droppings. *Afr J Biotechnol*. 2010;9(8): 2.675-82.
 43. Kabala C, Singh BR. Fraction and mobility of copper, lead and zinc in the vicinity of a copper smelter. *J Environ Qual*. 2001;30(2):485-492.
Available:<https://doi.org/10.2134/jeq2001.302485x>
 44. Narwal RP, Singh RP, Salbu B. Association of cadmium, zinc, copper, and nickel with components in naturally heavy metal-rich soils studied by parallel and sequential extractions. *Comm Soil Sci Plant Anal*. 1999;30(7-8):1209-1230.
Available:<https://doi.org/10.1080/00103629909370279>
 45. Nyle CB, Ray RW. *Nature and properties of soils*. 3rd edition. 2005;663:33-34.
 46. Tsetimi GO, Okieimen FE. Chelate-assisted phytoextraction of metals from chromated copper arsenate (CCA) contaminated soil. *J Environ Chem Ecotoxicol*. 2011;3(8):214-224.
Available:https://academicjournals.org/article/article1379492584_Tsetimi%20and%20Okieimen.pdf
 47. Hazelton PA, Murphy BW. *Interpreting soil test results: What do all the numbers mean?*. CSIRO Publishing; Melbourne; 2007.
 48. Smith SR. Organic contaminants in sewage sludge (biosolids) and their significance for agricultural recycling. *Philos Trans A Math Phys Eng Sci*. 2009; 367:4005-4041.
Available:<https://doi.org/10.1098/rsta.2009.0154>
 49. Temiz A, Yildiz UC, Nilsson T. Comparison of copper emission rates from wood treated with different preservatives to the environment. *Build Environ*. 2006;41(7): 910-914.
Available:<https://doi.org/10.1016/j.buildenv.2005.04.001>
 50. Kartal SN, Hwang WJ, Imamura Y. Evaluation of effect of leaching medium on the release of copper, chromium, and arsenic from treated wood. *Build Environ*. 2007;42(3):1188-1193.
Available:<https://doi.org/10.1016/j.buildenv.2005.12.009>
 51. Jang YC, Townsend TG, Ward M, Bitton G. Leaching of arsenic, chromium, and copper in a contaminated soil at a wood preserving site. *Bull Environ Contam Toxicol*. 2002;69:808-16.
Available:<https://doi.org/10.1007/s00128-002-0132-4>

52. Zagury GJ, Samson R, Deschenes L. Occurrence of metals in soil and ground water near chromated copper arsenate-treated utility poles. *J Environ Qual.* 2003;32:507-514. Available:<https://doi.org/10.2134/jeq2003.5070>
53. Robinson B, Greven M, Green S, Sivakumaran S, Davidson P, Clothier B. Leaching of copper, chromium, and arsenic from treated vineyard posts in Marlborough, New Zealand. *Sci Total Environ.* 2006;364(1-3):113-123. Available:<https://doi.org/10.1016/j.scitotenv.2005.07.012>
54. Stilwell DE, Gorny KD. Contamination of soil with copper, chromium, and arsenic under decks built from pressure treated wood. *Bull Environ Contam Toxicol.* 1997; 58:22-29. Available:<https://doi.org/10.1007/s001289900295>
55. Gress J, de Oliveira LM, da Silva EB, Lessl, JM, Wilson PC, Townsend T, Ma LQ. Cleaning-induced arsenic mobilization and chromium oxidation from CCA-wood deck: Potential risk to children. *Environ Int.* 2015;82: 35-40. Available:<https://doi.org/10.1016/j.envint.2015.04.012>
56. Toth G, Hermann T, DaSilva MR, Montanarella L. Heavy metals in agricultural soils of the European Union with implications for food safety. *Environ Int.* 2016;88:299-309. Available:<https://doi.org/10.1016/j.envint.2015.12.017>
57. UNEP. Environmental risks and challenges of anthropogenic metals flows and cycles. In: vander Voet E, Salminen R, Eckelman M, Mudd G, Norgate T, Hirschier R, (Eds). *A Report*; 2013.
58. Tokalioğlu S, Kavtal S, Gultekin A. Investigation of heavy metal uptake by vegetables growing in contaminated soil using the modified BCR sequential extraction method. *Int J Environ Anal Chem.* 2006;88(06):417-430. Available:<https://doi.org/10.1080/03067310500352387>
59. Brown SL, Chaney RL, Angle JS, Baker AM. Zinc and cadmium uptake by hyperaccumulator *Thlaspi caerulescens* and metal tolerant *Silene vulgaris* grown on sludge amended soils. *Environ Sci Technol.* 1995;29(6):1581-1585. Available:<https://doi.org/10.1021/es00006a022>
60. Munoz M, Pena L, Halloroms JO. Use of an industrial by product as liming source. *J Agric Univ Puerto Rico.* 1994;78(3-4):73-86. Available:<https://doi.org/10.46429/jaupr.v78i3-4.4276>
61. Australian Pesticides and Veterinary Medicines Authority (APVMA). *Toxicological assessment part one and two*; 2005.
62. Wang S, Mulligan CN. Effects of three low-molecular-weight organic acids (LMWOAs) and pH on the mobilization of arsenic and heavy metals (Cu, Pb, and Zn) from mine tailings. *Environ Geochem Health.* 2013; 35(1):111-118. Available:<https://doi.org/10.1007/s10653-012-9461-3>
63. Kumpiene J, Ragnvaldsson D, Lövgren L, Tesfalidet S, Gustavsson B, Lättström A, et al. Impact of water saturation level on arsenic and metal mobility in the Fe-amended soil. *Chemosphere.* 2009;74: 206–215. Available:<https://doi.org/10.1016/j.chemosphere.2008.09.068>
64. Wang SL, Mulligan CN. Enhanced mobilization of arsenic and heavy metals from mine tailings by humic acid. *Chemosphere.* 2009;74:274–279. Available:<https://doi.org/10.1016/j.chemosphere.2008.09.040>
65. Asagba EU, Okieiman FE, Osokpor J. Screening and speciation of heavy metal contaminated soil from an automobile spare-part market. *Chem Spec Bioavail.* 2007;19:9-15. Available:<https://doi.org/10.3184/095422907X198022>
66. Zhou LX, Wong JWC. Effect of dissolved organic matter from sludge compost of soil on copper sorption. *J Environ Qual.* 2001; 30:878-883. Available:<https://doi.org/10.2134/jeq2001.303878x>
67. Xu H, Allard B, Grimvall A. Effects of acidification and natural organic materials on the mobility of arsenic in the environment. *Water Air Soil Pollut.* 1991; 57-58:269-278. Available:<https://doi.org/10.1007/BF00282890>
68. Placek A, Grobelak A, Kacprzak M. Improving the phytoremediation of heavy metals contaminated soil by use of sewage

- sludge, *Int J Phytoremed.* 2016;18:(6):605-618.
Available:<https://doi.org/10.1080/15226514.2015.1086308>
70. Davenport JR, Peryea FJ. Phosphate fertilizers influence leaching of lead and arsenic in a soil contaminated with lead arsenate. *Water Air Soil Pollut.* 1991; 57:101–110.
Available:<https://doi.org/10.1007/BF00282873>
71. Sadiq M, Zaidi TM, Mian AA. Environmental behaviour of arsenic in soils: Theoretical. *Water Air Soil Pollut.* 1983;20:369–377.
72. Masscheleyn P, Delaun R, Patrick WH. Effect of redox potential and pH on arsenic speciation and solubility in a contaminated soil. *Environ Sci Technol.* 1991;25:1441-1419.
Available:<https://doi.org/10.1007/BF00208511>
73. James BR. Chemical transformation of chromium in soils relevance to mobility, bioavailability and remediation. *The chromium file*; 2002.
74. Fendorf SE. Surface reactions of chromium in soils and waters. *Geoderma.* 1995;67:55-71.
Available:[https://doi.org/10.1016/0016-7061\(94\)00062-F](https://doi.org/10.1016/0016-7061(94)00062-F)
75. Sass BM, Rai D. Solubility of amorphous chromium (III)-iron(III) hydroxide solid solutions. *Inorg Chem.* 1987;26:2228–2232.
Available:<https://doi.org/10.1021/ic00261a013>
76. Appelo CAJ, Posma D. *Geochemistry, groundwater and pollution.* 2nd ed. The Netherlands: A. A. Balkema Publishers; 2000.
77. Prado AGS, Airoidi C. Humic acid-divalent cation interactions. *Thermochim Acta.* 2003;405:287–292.
Available:[https://doi.org/10.1016/S0040-6031\(03\)00196-5](https://doi.org/10.1016/S0040-6031(03)00196-5)
78. Tyler LD, McBride MB. Mobility and extractability of cadmium, copper, nickel and zinc inorganic and mineral soil columns. *Soil Sci.* 1982;134:198–205.
79. Chirenje T, Rivero C, Ma LQ. Effects of humic and fulvic acid on As and Cr leachability in wood ash-amended soil columns. *Soil Sediment Contam.* 2002;11: 359–375.
Available:<http://rmag.soil.msu.ru/articles/453.pdf>
80. Benedetti MF, Miline CJ, Kinniburgh DG, Van Riemsdijk WH, Koopal LK. Metal ion binding to humic substances: Application of the non-ideal competitive adsorption model. *Environ Sci Technol.* 1995;29:446–457.
Available:<https://doi.org/10.1021/es00002a022>

© 2020 Nakiguli et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<http://www.sdiarticle4.com/review-history/61001>