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The potential for heavy metal pollution in crops from urban and peri urban horticultural farms in the Gaborone environs: a review

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LCO literature search. FP corresponding author and graduate student supervisor. MO critical analysis of draft review. TM-J project team member. TM project team member. JOA project team member and project conceptualization.

ABSTRACT

The introduction of urban and peri-urban agriculture (UPA) is usually characterized by high input intensity. This intensive use of chemical fertilizers, pesticides, wastewater, sludges and industrial effluents may lead to accumulation of potentially toxic metals in the soil, increasing the geological background levels and exceeding the capacity to immobilize them. Besides being environmental pollutants of which the toxicity is a problem of increasing significance for ecological reasons, heavy metal accumulation in the food chain is highly dangerous for human health. The objective of this review was to highlight the potential problems that may arise as a consequence of irrigating crops with sewage water as well as using fertilizers and pesticides. A review of literature has shown that different types of fertilizers contain some quantities of heavy metals that may buildup in the soil as well as be taken up by crops. In addition to using fertilizers, the use of treated and sometimes partially treated and untreated water by UPA farmers around Gaborone may lead to heavy metal accumulation in soil as well as in crops, posing a danger to human beings. In Botswana there is limited information concerning heavy metal accumulation in soils even though there is a high use of agrochemicals in vegetable production in UPA land use systems. Lack of such information necessitates research on the impact of the application of fertilizer, sewage water (treated and untreated) and metal-based pesticides on the quality of the vegetable produce coming from UPA.

Keywords: Agrochemicals, Botswana, fertilizer, soil contamination, treated sewage effluent, UPA

INTRODUCTION

The United Nations (UN) Population Fund estimates that more than 50% of the world's population lives in urban and peri urban centres (UNPF, 2007). Statistics Botswana reported the same trend where urban dwellers constitute more than 60% of the country's population in 2011 (CSO, 2011). The dramatic increase in urban dwellers as people migrate from rural areas to cities, calls for improved food supply and distribution to reduce levels of urban food insecurity without compromising farmer incomes (FAO, 2006). The Botswana Ministry of Agriculture has advocated for the introduction of urban agriculture to meet demands for food in urban areas (Madisa et al., 2010). This ministry is responsible for ascertaining food security in Botswana through programmes such as ISPAAD (Integrated Support Programme for Arable Agriculture Development). For example, horticulture has been identified as an area that can assist in securing food and eradicating poverty. Through the CEDA (Citizen Entrepreneur Development Agency), millions have been spent on supporting horticultural projects. But because of the semi-arid to arid nature of the country, shortage of water for irrigation remains a challenge. So, because good quality water is scarce, the use of treated sewage water is encouraged. Also, because soils are generally poor, fertiliser use is common practice (Pule-Meulenberg and Batisani, 2004). In addition, the use of pesticides in vegetable production in UPA land use system is high (Obopile et al., 2008; Gobusamang et al., 2012). Thus, the introduction of urban agriculture and peri-urban agriculture is usually characterized by high input intensity. However, the intensive use of chemical fertilizers, pesticides, wastewater, sludges and industrial effluents has been associated with hazardous metals (Keraita and Drechsel, 2002; Amoah et al., 2005). Thus, the continuous use, particularly of wastewater may lead to the accumulation of potentially toxic metals such that the geological background levels are increased and the capacity to immobilize them is greatly exceeded (Wei and Yang, 2010; Ugbaje and Agbenin, 2012). Generally, heavy metals occur naturally in all soils in minute quantities, but can accumulate in agricultural soils from various sources, such as fertilizers, organic supplements, atmospheric deposition and urban industrial activities (Modaihsh et al., 2004). Elevated concentrations of heavy metals in soil have been shown to have adverse effects on human and animal health when these metals are taken up by the crops and transferred up the food-chain or are leached to the ground water (Modaihsh et al., 2004; Fuentes et al., 2008; Ugbaje and Agbenin, 2012).

Heavy metals are significant environmental pollutants, and their toxicity is a problem of increasing significance for ecological, nutritional and environmental reasons. They are non-biodegradable and persistent environmental contaminants. Heavy metal bioaccumulation in the food chain can be especially dangerous to human health. These metals enter the human body mainly through two routes namely: inhalation and ingestion, with ingestion being the main route of exposure to these elements. Vegetables constitute essential diet components by contributing proteins, vitamins, iron, calcium and other nutrients, which are usually in short supply. Vegetables take up metals by absorbing them from contaminated soils, as well as from deposits on different surfaces of the vegetables exposed to the air from polluted environments.

Food contamination by heavy metals depends both on their mobility in the soil and their bioavailability. Quantifying the levels of potentially toxic metals in the soil has been shown not to reflect their bioavailability and potential to contaminate the food chain, but to be simply an indication of the soil levels in reference to some safety levels established elsewhere (Silva et al., 2008). For example, Agbenin et al. (2010) and Abdu et al. (2011), reported that leafy vegetables could accumulate potentially toxic metals above the safe limits for human consumption in urban gardens from West Africa where the concentrations of the metals in the soils were two to three times lower than allowable concentrations delineated by the European Union. Information on the distribution of heavy metals in their various chemical forms should be employed to assess the potential contamination risk and ensuing environmental damage. It is the chemical form of a potentially toxic metal that determines its reactivity, and hence its bioavailability, toxicity and mobility in the soil environment (Huong et al., 2010; Ugbaje and Agbenin, 2012). Therefore knowledge of the interactions between heavy metals and the soil matrix is required to judge their environmental impact.

The most common way to study the behavior of heavy metals in soils is by treatment with extractants of different chemical properties (Huong et al., 2010). A typical chemical extraction scheme includes the extraction of metal forms from a soil sample with different reagents in sequence, starting with a weak solvent, followed by a stronger one to more aggressive reagents (Ugbaje and Agbenin, 2012). Sequential chemical extraction techniques according to Huong et al. (2010) have received considerable attention because they provide operational and practical methodology for differentiating varying labile forms of a potentially toxic metal in soils.

Farmers around Gaborone city engaged in UPA use secondary treated wastewater and underground water for irrigation and high inputs (agrochemicals) to increase their crop yields, but the dynamics of potentially toxic metals movement, bioavailability and the associated health risk for vegetable consumers has not been widely investigated in the area. The aim of this review is to highlight the potential problems that may arise as a consequence of irrigating crops with treated sewage effluent combined with the use of fertilisers.

Effect of inorganic fertilizers on heavy metal accumulation in soils and plants

Crop fertilizers have adequately justified their introduction as a necessary option in agriculture. However, application of fertilizers is considered one of the potential routes heavy metals enter the agricultural soils. Inorganic fertilizers such as phosphatic fertilizers and different combinations of NPK may also influence the distribution of heavy metals among various fractions by altering soil properties such as pH and surface charge or by reacting with heavy metals.

Phosphatic fertilizers have been shown to contain heavy metals as minor constituents (Modaihsh et al., 2004; Ramadan and Al-Ashkar, 2007; Ajayi et al., 2012) and thus are a potential source of heavy metal pollution. It is assumed that these heavy metals are transferred to the fertilizers during their processing (Modaihsh et al., 2004). Ramadan and Al-Ashkar (2007), reported that on average phosphate rock contained 11, 25, 188, 32, 10, and 239 mg kg^{-1} of As, Cd, Cr, Cu, Pb, and Zn respectively. This is particularly relevant for Botswana because almost all soils are highly deficient in P and hence for arable production, this essential nutrient must be applied.

So far, there are no known studies that have quantified the level of heavy metals in different fertilizers, nor is it a requirement for merchants to know the concentration of heavy metals in fertilizers. For example, Williams and David (1973) have shown that the average Cd content of Australian fertilizers manufactured in New South Wales over a 12 year period was 42 ppm. In Botswana such information is lacking, despite the fact that all UPA farmers apply fertilizers. A study by Thomas et al. (2012) also showed that phosphate fertilizers contributed greatly to heavy metal content in soils. In that study, a pot experiment to assess the effect of phosphate fertilizer on heavy metal uptake by *Amaranthus caudatus* indicated that after harvesting, the concentration of Cu and Zn in the soil had increased by 400%, Cd increased by over 100%, but Pb increased insignificantly. The increased concentration of heavy metals in the soil after the experiment showed that phosphate fertilizer contributed greatly to heavy metal content in soils.

However, it is not only the phosphate fertilizers that pollute soils and eventually vegetables grown on them, but also NPK combinations were shown to increase heavy metal concentrations. For example, Abdul et al. (2011) reported that fertilizer application (NPK) contributed annually 30-2100 g cadmium ha^{-1} and 50-17600 g zinc ha^{-1} to soils in Nigeria. A few studies however contradicted the results obtained by the studies mentioned above. Ajayi et al. (2012) compared soil samples from fields that had been under extensive use of NPK fertilizer for over 10 years to those from non-fertilized ones. Their results did not show significant differences between metal concentrations of fertilized sites and those of non-fertilized ones. In another study, Jones et al. (2002), established that fertilized soils in general had significantly lower levels of available and total metals than those of non-fertilized soils. Their findings suggested that long-term fertilization did not increase metal concentration in soils. However, it is not certain if these studies used similar types of fertilizers containing similar proportions of heavy metals. It is also not clear what type of soils were used in both experiments. It is evident that investigations into possible pollution of soils by fertilizers with heavy metals are dependent on several factors including but not limited to the origin of fertilizer, type of fertilizer, type of soil, and soil pH. Thus, it becomes difficult to extrapolate data across different environments, hence necessitating that studies be carried out for every particular locale such as the Gaborone environs in Botswana.

Effect of organic fertilizers on heavy metal accumulation in soils and plants

Organic matter has an important role in controlling the mobility of heavy metals in soils. It may decrease the available concentrations of heavy metals in soils by precipitation, adsorption or complexation processes (Bernal et al., 2007). Organic matter lowers the uptake of heavy metals by plants, as shown by Sampanpanish and Pongpaladisai (2011), who studied the effects of organic fertilizer on cadmium uptake by rice grown in contaminated soil. Their results revealed that Cd uptake by both above and below ground parts of rice cropped in soil with organic fertilizer was lower than that without organic fertilizer. Similar results had been earlier reported by Agelova et al. (2010) who conducted a comparative research on the impact of organic soil additives (peat, compost and vermi compost) on the quantity of mobile forms of Pb, Zn, Cd, and Cu and their uptake by potato (*Solanum tuberosum* L.) plants. Organic amendments led to an effective immobilization of Pb, Cu, Zn and Cd phyto accessible forms in soil and decreased heavy metal content in the potato peel and tubers.

On the other hand organic matter, depending on its source, can contribute to the accumulation of heavy metal in soil. Wu et al*.* (2013) found that use of farm manure contributed to the accumulation of heavy metals in vegetable gardens; they further stated that the use of manure as the main source of plant nutrients could increase heavy metal content soil. The same results were recorded by Ramadan and Al-Ashkar (2007), whereby use of 100% and 75% chicken manure led to accumulation of Pb and Fe in soil and in tomato organs (roots and stems). Heavy metals concentration in farm manure is said to owe much to the intensification of animal husbandry that led to the use of feed additives such as heavy metals and that of veterinary antibiotics to control animal diseases in all classes of livestock including poultry. However accumulation is usually mostly in surface soils, and this can have detrimental effects on most plant species (Wu et al., 2013).

In Botswana, few known studies regarding the effect of organic matter on heavy metal accumulation have been carried out (Nkegbe, 2005). The study by Nkegbe (2005) assessed heavy metal composition in Glen Valley dry sludge and found that all the metals were within ranges expected for sludge use and disposal of municipal wastewater sludge. Besides the use of sludge, (which is not permitted for vegetable production in Botswana), the most commonly used form of organic matter is chicken manure. Thus it would be useful to study properties of soils amended with chicken manure. But whether such soils have high concentration of heavy metals such as Cu, Ni, Zn Pb, Cr and Cd will be dependent of the quality of the diet that was fed to the chicken. Therefore, studies on the quality of chicken feed with respect to contents of heavy metals are also required.

Effect of irrigation with wastewater on heavy metal accumulation in soils and plants

Besides inorganic and organic fertilizers, wastewater is also commonly used in urban and peri-urban agriculture, especially in semi-arid to arid areas of the world where good quality water is in short supply. However, the use of wastewater enriches soils with heavy metals to concentrations that may pose environmental and health risks in the long term (Behbahaninia et al., 2010; Galavi et al., 2010; Ta'any et al., 2013). Abedi-Koupai et al. (2006) conducted a study on Aridisols, using sugar beet, maize and sunflower to determine the effect of treated wastewater on soil chemical and physical properties. Their findings showed a significantly increased concentration of Pb, Mn, Ni, and Co in the soil. Similar results were obtained by Kalavrouziotis et al. (2009) using treated wastewater for irrigation of *Brassica oleracea*; they reported accumulation of Cd, Pb, and Zn in both soil and plants, especially in the edible plant parts. However, Ta'any et al. (2013), investigating the appropriateness of treated wastewater for cultivation of salt-tolerant fodder plants (*Tamarix sativa, Medicago sativa, Pennisetum glaucum and Atriplex hallimus*), reported an insignificant accumulation of heavy metals in irrigated soils and plants, although the irrigation wastewater had a metal concentration above Jordanian maximum permissible limits.

In Botswana, the use of wastewater in agriculture is relatively recent. Hence, few studies on the effects of irrigation with treated wastewater on heavy metal accumulation have been conducted. Emongor et al*.* (2005) reported lower levels of heavy metal content in the treated wastewater than the recommended limits by FAO and the Botswana government guidelines for irrigation water quality. Even though heavy metal concentration is lower in treated wastewater compared to the recommended limits, a potential for buildup was shown in a study by Aganga et al. (2005), whereby soil analyzed exhibited relatively high levels of heavy metals compared to the treated sewage effluent used for irrigation. This buildup can clearly pose a threat in the long term. Dikinya and Areola (2009) assessed heavy metal concentration in soils in Glen Valley irrigated with treated wastewater, cultivated to different crops such as maize, spinach, olive and tomatoes. The results revealed that wastewater irrigated soils had higher levels of Cd, Ni and Cu compared to the FAO heavy metal threshold values for crop production. Mercury, Pb and Zn were lower than the maximum threshold values recommended for crop production. A striking result from the study by Dikinya and Areola (2009) was the finding that heavy metal concentrations, with the exception of Cd and Hg, from soils of control sites were higher than on the cultivated plots. This prompted them to speculate that the uptake of some of the metals by plants under irrigation had been high and as a result significantly lowered the metal concentration in the soils. Studies conducted in Botswana using treated wastewater have not investigated the bioavailability of these heavy metals, their potential to contaminate the food chain, and their concentration in crops. Therefore a comprehensive analysis of heavy metals in both soil and crops to assess the risk posed to both human and animal health would be worthwhile.

Effect of pesticides on heavy metal accumulation in soils and plants

Several heavy metal based pesticides are used to control diseases of grains, fruits and vegetables and form therefore, a source of heavy metal pollution of the soil. Aoyama and Tanaka (2013) reported that surface soils of apple orchards in Japan were polluted with Cu, Pb and As due to long term use of metal based pesticides. A similar study by Chiroma et al*.* (2007) also reported high accumulation of Cd, Pb and Cu in leaves of two species of spinach (maroon and green) treated with pesticides (DELVAP 1000 EC) compared to untreated ones. The levels of Cd, Pb and Cu in leaves of maroon spinach treated with pesticides were respectively 6.8, 1.4 and 18.6 times higher than the maximum tolerable levels in plants of 30µg/g (Cd), 300 µg/g (Pb), and 100 µg/g (Cu). In green spinach treated with pesticides the levels of Cd and Cu in leaves were respectively 4.9 and 14.7 times higher than maximum tolerable levels.

Even though there is a high use of pesticides in vegetable production in UPA land use systems in Botswana, limited information is available concerning heavy metal accumulation in soils where pesticides are used (Obopile et al., 2008; Gobusamang et al., 2012). Lack of such information necessitates research on the impact of metal-based pesticides on the quality of the vegetable produce coming from UPA.

Uptake and accumulation of heavy metals in vegetables

Plants have the ability to absorb heavy metals from the environment (soil, water and air). Hence, the mobilisation of different trace elements at toxic levels in the environment can result in accumulation of these pollutants in the food chain. In contamination of soils by metals, soil to plant transfer of heavy metals is the major pathway to human exposure (Cui et al., 2004). Heavy metals are mostly transported via the plant roots through solute movement, mass flow and diffusion. Plant uptake of mobile ions present in the soil solution is largely dependent on the total quantity of the ions (Abdu et al*.,* 2011). Roots may modify movement of heavy metals in the soils by producing root exudates that form complexes and chelates with metal ions. Uptake of metals by plants differs depending on the source, for example, from bio-solids and soluble salts (Silveira et al., 2002). When metals are added to soil as soluble salts, a linear response is anticipated, that is, as the concentration of the metal increases in the soil, there is a corresponding increase in the metal concentration in plants. This was confirmed by Intawongse (2007), who performed a study on uptake of heavy metals by vegetables grown on contaminated soils (Cr, Cd, Mn, Fe, Ni, Cu, Zn, Mo and Pb) using lettuce, spinach, radish and carrot as test crops. Results of that study revealed that, with the exception of Cr, metal concentration (Cd, Mn, Fe, Ni, Cu, Zn, Mo and Pb) in lettuce, spinach, carrot and radish depended on the concentration of the (total) metal in the soils in which the plants were grown, that is, accumulated metal contents in the plants were increased when higher levels of metal contamination in the soils were applied. This result confirmed the theory by Silveira et al. (2002) that a linear response is expected when soluble salts are added to soils.

Silveira et al. (2002) also showed that bio-solids could prevent excessive metal uptake by plants. This protective mechanism was attributed to the presence of adsorptive materials in the bio-solid such as organic matter and amorphous iron oxides. Therefore, when soils are low in organic matter and the added fertilizers are inorganic in nature, the concentration of metallic and metalloid ions can be expected to be higher in both soils and plants. Although worldwide many studies (Intawongse, 2007; Huong et al., 2010; Abdu et al*.,* 2011; Akan et al., 2013) have assessed the concentration of heavy metals in soils and their uptake by plants, very few have been conducted in Botswana where soils are low in organic matter and have slightly acidic to acidic pH values (Kayombo et al., 2005; Pule-Meulenberg et al., 2005). A study by Lacatusu and Lacatusu (2008) conducted in Romania showed that the quality of vegetables and fruits from crops grown in polluted soils was directly proportional to the concentration of the pollutant. Results from that study indicated concentrations of Cd and Pb that exceeded maximum allowable limits up to 2.5 times and 11 times respectively (in root vegetables of carrots, radish and potatoes). In leafy vegetables (lettuce, parsely, dill), Cd and Pb were 7 times and 17 times respectively higher than maximum allowable limits.

Uptake of heavy metals by vegetable crops grown in UPA farms has not widely been studied in Botswana. The few studies conducted were in Glen Valley, an area where all farmers irrigate using treated sewage effluent. For example, Adekanmi (2010) compared the uptake of Cr and Ni in tomato plants irrigated with treated wastewater on soils amended with sludge, with uptake in plants irrigated with tap water on sludge absent soils. Results from that study showed that accumulation of Cr in tomato leaves and fruits increased as the pH of treated wastewater increased from slightly acidic (pH 5.0 to pH 6.0) to a neutral pH of 7.0. The FAO permissible limits for effluent quality for Cr were exceeded as a result of irrigation with treated wastewater and the use of sludge amended soil for tomato production. For Ni, neither the

FAO permissible limits nor the Botswana Bureau of Standards effluent quality limits for Ni were exceeded.

From the studies described, it is clear that crops grown from contaminated soil accumulate metals in their tissues, and that crops differ in their heavy metal uptake and accumulation. It is strongly suggested that these kind of studies be repeated in Botswana and investigate different heavy metals and vegetables to establish their uptakes so that health precautions could be taken if required.

Bioavailability of heavy metals in soils

It is generally accepted that total metal content in soils is not a good indicator of toxicity risk to plants or humans. Only a portion of the total quantity of pollutant present in soil is potentially available for uptake by organisms. This phenomenon is referred to as biological availability (bioavailability) of a chemical (Kim et al., 2009). Bioavailability is defined as the fraction of a contaminant in a particular environmental matrix that is absorbed by an organism via a specific exposure route (Kim et al., 2009). Another generally accepted definition of bioavailability is the fraction of the total amount of chemical present in a specific environment compartment, that within a given time frame, is either available or can be made available for uptake by (micro) organisms or plants or by ingestion of food (Peijnenburg and Jager, 2003). Heavy metals in soil may be found in one or more of the following forms: dissolved (in soil solution), exchangeable (organic and inorganic components), as structural components of the lattices of soil minerals and as insoluble precipitates (such as carbonates) with other soil components (Aydinalp and Marinova, 2003). Dissolved and exchangeable forms are readily available to plants while the other two are potentially available in the longer term. Heavy metals and metalloids can be involved in a series of complex chemical and biological interactions. In their water soluble, exchangeable and carbonate fractions, heavy metals exhibit great mobility and bioavailability (Huong et al., 2010). Metal toxicity and availability are closely related to their fraction in bioavailable form (Kim et al., 2009).

The bioavailability of metals in soils depends on their form and concentration in the parent material and their input through fertilizers, sewage sludge and atmospheric deposition (Modaihsh et al., 2004). Bioavailability is also affected by leaching processes, adsorption and desorption from the solid phase and mineralization of the organic matter. Bioavailability of heavy metals will subsequently be controlled by a number of soil properties which regulate these processes such as low pH and low organic matter. Due to prevailing environmental conditions, levels of organic matter in most soils in Botswana are low which may enhance the bioavailability of heavy metals and metalloids. Large soil particle size can also result in greater bioavailability of metals by reducing adsorption and increasing dissolved metal contents. The majority of soils in Botswana are sandy, with large particle sizes (Kayombo et al., 2005; Pule-Meulenberg et al., 2005). Other influential soil properties include pH, organic matter content, cation exchange capacity, redox conditions, the presence of hydroxides and other ions.

Soil pH

Hydrogen ion activity (pH) is one of the most important factors governing metal speciation, solubility from mineral surfaces, transport and eventual bioavailability of metals in aqueous solution (John and Leventhal, 1995). Soil pH affects both solubility of metal hydroxide minerals and adsorption – desorption processes. Many researchers have shown that soil pH has a large effect on metal bioavailability. Evans et al. (1995) investigated the role of changes in pH to the content of soluble Cd, Co, Cr, Cu, Pb, Ni and Zn in soils to which sewage sludge had been applied. The results showed that for all the metals, their contents in soils increased markedly as the pH decreased below pH 5. In another study, Porizovsky and Tsadilas (2003) conducted a study to determine lead (Pb^{2+}) sorption by an Alfisol and zeolite at different pH values (pH 3, 4, and 5) to establish the relationship between the amount of Pb retained and ions displaced from the soil into the solution. They found that higher pH enhanced sorption of lead and that retention of lead by soil was accompanied by displacement of both Ca^{2+} and H^+ cations.

Soil organic matter

Soil organic matter (SOM) is an important component of the soil since it has a high surface area, and has functional groups that are Lewis bases (e.g. carboxyl and phenol groups) with which metals can form chemical bonds (Strawn and Sparks, 2000). Soil organic matter can be of plant, animal or microbial origin and may be relatively fresh or highly decomposed and transformed. Organic matter improves the physical properties of soil through the stabilization of soil aggregates resulting in better aeration of the soil and better water retention. Chemically, organic matter increases the overall negative charge and thus adsorption sites (cation exchange) of the soil. It tends to be highly reactive toward ionic and polar contaminants because ionisable functional groups within organic matter (e.g. carboxylate, phenolics, amino and phosphate groups) have a tendency of binding metal ions and forming complexes (Levonmäki et al., 2006). Therefore organic amendments can decrease heavy metal bioavailability, shifting them from ‘‘plant available’’ forms to fractions associated with SOM, carbonates or metal oxides.

Several studies have investigated the influence of SOM content on metal mobility and bioavailability. Schaecke et al. (2002) evaluated biosolid application rates (equivalent 82-330 ton ha^{-1} dry matter) incorporated in 0-0.25 m depth of a Chernozem. This investigation aimed to study the fate of heavy metals Zn, Cd, Cu, Ni, Pb, and Cr, and to determine their concentration in the soil fractions. Eleven years after the last application, metals supplied with the sludge had moved 50 cm in depth. Their results showed that the concentrations of Zn, Cd, Cu, Ni, and Cr in the saturation extract of the sampled horizons were partly linked to the dissolved organic carbon movement in the soil. Alamgir et al. (2011) investigated the effect of farm yard manure on Cd and Pb absorption by *Amaranthus oleracea* L plants. Their results showed that application of farm yard manure in soil significantly decreased Cd and Pb content in *Amaranthus oleracea.* Similarly, Sklodowski et al. (2006) reported decreased bioavailability of Cd, Pb and Zn to plants with an increase of the amendment dosage of organic matter from brown coal. The objective of their study was to prove the feasibility of using brown coal-derived preparations for reducing bioavailability of cadmium, lead and zinc to higher plants.

Cation exchange capacity

Cation exchange capacity (CEC) is defined as the sum total of the exchangeable cations that a soil can adsorb (Brady and Weil, 1999). Cation exchange capacity is directly related to the soils' capacity to adsorb heavy metals. A greater CEC value means that more exchange sites on soil minerals are available for metal retention. Thus, soils with high clay content such as the Vertisols of Glen Valley in Botswana have a high potential to adsorb heavy metals due to their high overall negative charge of montmorillonitic clay. However, the presence of competitive cations can affect metal adsorption in soils. For instance, Ca^{2+} competes effectively with cationic heavy metals for adsorption sites.

Redox conditions

Redox is a short term for a reduction-oxidation reaction, the process involving the flow of electrons from a reducing agent (reductant) to an oxidizing agent (oxidant). Soil redox potential can influence the solubility of heavy metals. When conditions are oxidative, the solubility of heavy metals increases with decreasing pH (Schaecke et al., 2002). But, in reducing conditions such as when the soil is waterlogged, the solubility of Zn, Cu, Cd, and Pb is higher in alkaline pH values, as a result of the formation of stable soluble organomineral complexes. Gambrell et al. (1991) studied the effects of pH, redox potential and salinity on metal release from contaminated sediment. Their results indicated that substantial amounts of Cd and Zn were released under moderately acidic, oxidizing conditions, while under a slightly basic, strongly anaerobic environment, the metals were immobilized. It is therefore important to study heavy metal mobility and bioavailability in places that are irrigated. Depending on the amount of water added to the soil, prevailing conditions could be either reducing or oxidating with associated increases or decreases in heavy metal solubility.

Sesquioxides

The oxides of Fe, Mn and Al, which are commonly referred to as sesquioxides (hydrous oxides) play an important role in the chemical behaviour of metals in soils. They affect metal availability in soils mainly by specific adsorption to surface hydroxyl groups, by non-specific adsorption (exchange) and by preciptation as the discrete metal oxide or hydroxide (Reichman, 2002).

Silveira et al. (2002) studied Cu adsorption in surface (0–0.2 m) and subsurface samples of three soils (a heavy clayey textured anionic Acrudox, a medium textured anionic "xanthic" Acrudox and a rhodic Hapludalf), before and after the removal of organic matter and/or iron oxides. When soil pH was below the zero point charge, the removal of iron oxides increased the retention of Cu, more likely because of a reduction in the repulsion forces between the positively charged surface and the metal.

CONCLUSIONS

This review was undertaken to address the lack of information on the effect of the application of agrochemicals and the use of treated sewage effluent on the accumulation of heavy metals in UPA soils. Such information has a direct bearing on the health risks to consumers of agricultural produce from such soils. A review of literature has shown that different types of fertilizers contain some quantities of heavy metals and that continuous application may lead to a buildup in the soil as well as uptake by crops. Furthermore, organic soil amendments such as sewage sludge and animal manures could also contain some quantities of heavy metals, their concentration in animal manures being dependent on the quality of feedstuff. Hence the need to investigate the effect of organic soil amendments on the bioavailability of heavy metals in various soil types of Botswana. In addition to using fertilizers, the use of treated and sometimes partially treated and untreated wastewater by UPA farmers around Gaborone is common practice. However, the bioavailability of heavy metals and the potential to contaminate the food chain resulting from the use of wastewater has not systematically been studied in Botswana. Therefore, a comprehensive analysis of trace element levels in both soils and crops to assess the risk posed to both human and animal health would be worthwhile. There is also limited information available concerning heavy metal accumulation in soils where pesticides are used, even though there is a high use of pesticides in vegetable production in UPA land use systems. Lack of such information necessitates research on the impact of metal-based pesticides on the quality of the vegetable produce coming from UPA. In conclusion, there is need to profile heavy metal background levels under UPA farming systems in Botswana.

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CONFLICT OF INTEREST

None.

REFERENCES

Abdu, N., Abdulkadir, A., Agbenin, J.O. and Buerkerf, A. (2011). Vertical distribution of heavy metals in wastewater-irrigated vegetable garden soils of three West African cities. *Nutrient Cycling in Agroecosystems* 89: 387–397.

Abedi-Koupai, J., Mostafazadeh-Fard, B., Afyuni, B. and Bagheri, M.R. (2006). Effect of treated wastewater on soil chemical and physical properties in an arid region. *Plant Soil Environment* 52: 335–344.

Adekanmi, A.A. (2010). An investigation of chromium and nickel uptake in tomato plants irrigated with treated wastewater at the Glen Valley farm, Botswana. MSc thesis, University of Pretoria, South Africa.

Aganga, A.A., Machacha, S., Sebolai, B.,Thema, T. and Marotsi, B.B. (2005). Minerals in soils and forages irrigated with secondary treated sewage water in Sebele, Botswana. *Journal of Applied Sciences* 5: 155–161.

Agbenin, J.O., Danko, M. and Welp, G. (2010). Soil and vegetable compositional relationships of eight potentially toxic metals in urban garden fields from northern Nigeria. *Journal of the Science of Food and Agriculture* 89: 49–54.

Ahmed, A.B. and Bouhadjera, K. (2010). Assessment of metals accumulated in Durum wheat (*Triticum durum* Desf.), pepper (*Capsicum annuum*) and agricultural soils. *African Journal of Agricultural Research* 5: 2795–2800.

Ajayi, S.O., Odesanya, B.O., Avwioroko, A.O., Adebambo, G.S. and Okafor, B. (2012). Effects of long term fertilizer use on trace metal levels of soils in a farm settlement. *Journal of Agricultural Research and Development* 2: 44–51.

Akan, J.C., Kolo, B.G., Yikala, B.S. and Ogugbuaja, V.O. (2013). Determination of some heavy metals in vegetable samples from Biu local government area, Borno State, North Eastern Nigeria. *International Journal of Environmental Monitoring and Analysis* 1: 40–46.

Alamgir, M., Kibria, M.G. and Islam, M. (2011). Effects of farm yard manure on cadmium and lead accumulation in Amaranth (*Amaranthus oleracea* L.). *Journal of Soil Science and Environmental Management* 2: 237–240.

Amoah, P., Drechsel, P. and Abaidoo, R.C. (2005). Irrigated urban vegetables production in Ghana. Sources of pathogen contamination and health risk examination. *Irrigation and Drainage* 54: 49–61.

Angelova, V., Ivanova, R., Pevicharova, G. and Ivanov, K. (2010). Effect of organic amendments on heavy metals uptake by potato plants. In: Gilkes, R.J. and Prakongkep, N. (eds.) Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1–6 August 2010. Symposium 3.5.1 Heavy metal contaminated soils pp. 84–87.

Anon, (1994). Nickel and its compounds, priority substances list assessment report. National printers (Ottawa) Inc.

Aoyama, M. and Tanaka, R. (2013). Effects of heavy metal pollution associated with past use of metal-based pesticides on soil microbial biomass and microbial communities. *Journal of Environmental Protection* 4: 27–36.

Aydinalp, C. and Marinova, S. (2003). Distribution and forms of heavy metals in some agricultural soils. *Polish Journal of Environmental Studies* 12(5): 629–633.

Behbahaninia, A., Mirbagheri, S.A. and Nouri, J. (2010). Effects of sludge from wastewater treatment plants on heavy metals transport to soils and groundwater. *Iranian Journal of Environmental Health Science Engineering* 7: 401–406.

Chang, C., Chiang, H., Su, Z. and Wang, C. (2005). A sequential extraction method measures the toxic metal content in fly ash from a municipal solid waste incinerator. *Journal of the Chinese Chemical Society* 52: 921–926.

Chiroma, T.M., Abdulkarim, B.I. and Kefas, H.M. (2007). The impact of pesticide application on heavy metals (Cd, Pb and Cu) levels in spinach. *Leonardo Electronic Journal of Practices and Technologies* 11: 117–122.

CSO (2011). Annual agricultural survey report. Statistics Botswana. 200 pp.

Cui, Y., Zhu, Y., Zhai, R., Chen, D., Huang, Y., Qiu, Y. and Liang, J. (2004). Transfer of metals from soil to vegetables in and area near a smelter in Nanning, China. *Environmental International* 30: 785–791.

De Souza Silva, M.L., Trevizam, A.R. and Vitti, G.C. (2008). Copper and zinc quantification in contaminated soil as evaluated by chemical extractants. *Scietia Agricola* 65: 665–673.

Dikinya, O. and Areola, O. (2009). Comparative assessment of heavy metal concentration in treated wastewater irrigated soils cultivated to different crops in the Glen Valley, Botswana. *African Crop Science Conference Proceedings* 9: 351–355.

Emongor, V.E., Khonga, E.B., Ramolemana, G.M., Marumo, K., Machacha, S. and Motsamai, T. (2005). Suitability of treated secondary sewage effluents for irrigating horticultural crops in Botswana. *Journal of Applied Science* 5: 451–454.

Essington, M.E. (2004). Soil and water chemistry: an integrative approach. CRC Press LLC. New York. USA.

Evans, L.J., Spiers, G.A. and Zhao, G. (1995). Chemical aspects of heavy metal solubility with reference to sewage sludge amended soils. *International Journal of Environmental Analytical Chemistry* 59: 291–302.

FAO (1990). Revised general soil legend of Botswana. BOT/85/011. Botswana Government Printers, Gaborone, Botswana.

FAO (2006). The state of food insecurity in the world. Food and Agriculture Organization of the United Nations, Rome, Italy. 44 pp.

Fuentes, A., Llorens, M., Saez, J., Aguilar, M.I., Ortuno, J.F. and Meseguer, V.F. (2008). Comparative study of six different sludges by sequential speciation of heavy metals. *Bioresource Technology* 99: 517–525.

Galavi, M., Jalali, A. and Ramroodi, M. (2010). Effects of treated municipal wastewater on soil chemical properties and heavy metal uptake by sorghum (*Sorghum bicolor* L.). *Journal of Agricultural Science* 2: 235–241.

Gambrell, R.P., Wiesepape, J.B., Patrick, W.H.Jr. and Duff, M.C. (1991). The effects of pH, redox, and salinity on metal release from a contaminated sediment: *Water, Air and Soil Pollution* 57–58: 359–367.

Gobusamang, L., Obopile, M., Oagile, O., Madisa, M.E. and Assefa, Y. (2012). Urban vegetable farm workers beliefs and perception of risks associated with pesticide exposure: a case of Gaborone City, Botswana. *Journal of Plant Studies* 1(2): 114.

Huong, N.T.L., Ohtsubo, M., Li, L., Higashi, T. and Kanayama, M. (2010). Heavy metal contamination of soil and vegetables in wastewater-irrigated agricultural soil in a suburban area of Hanoi, Vietnam. *Communication in Soil Science and Plant Analysis* 41: 390–407.

Intawongse, M. (2007). Uptake of heavy metals by vegetable plants grown on contaminated soils: Their bioavailability and speciation. PhD thesis, Northumbria University, Thailand.

Islam, E., Yang, X., He, Z. and Mahmood, Q. (2007). Assessing potential dietary toxicity of heavy metals in selected vegetables and food crops. *Journal of Zhejiang University, Science B* 8: 1–3.

John, D.A. and Leventhal, J.S. (1995). Bioavailability of metals. In: du Bray, E.A. *Preliminary compilation of descriptive geo-environmental mineral deposit models*. U.S. Department of the Interior: U.S. Geological Survey Open-File Report: 95–831.

Jones, C.A., Jacobsen, J. and Lorbeer, S. (2002). Metal concentration in three Montana soils following 20 years of fertilization and cropping. *Communication in Soil Science and Plant Analysis* 33: 1401–1414.

Kalavrouziotis, I.K., Koukoulakis, P.H. and Papadopoulos, A.H. (2009). Heavy metal interrelationships in soil in the presence of treated wastewater. *Global NEST Journal* 11: 497–509.

Kayombo, B., Pule-Meulenberg, F., Moganane, B.G., Dikinya, O., Aliwa, J.N., Nsinamwa, M., Gaboutloe-loe, G., Patrick, C., Mzuku, M. and Machacha, S. (2005). Characterization of agriculture-related land degradation in eastern and western parts of Botswana. *Botswana Journal of Technology* 14: 1–10.

Keraita, B. and Drechsel, P. (2002). Wastewater use in informal irrigation in urban and peri-urban areas in Kumasi, Ghana. *Urban Agriculture Magazine* 8: 11–13.

Kim, K., Owens, G. and Naidu, R. (2009). Heavy metal distribution, bioaccessibility, and phytoavailability in long-term contaminated soils from lake Macquarie, Australia*. Australian Journal of Soil Research* 47: 166–176.

Lacatusu, R. and Lacatusu, A. (2008). Vegetables and fruits quality within heavy metal polluted areas in Romania. *Carpathian Journal of Earth and Environmental Sciences* 3(2): 115–129.

Levonmäki, M., Hartikainen, H. and Kairesalo, T. (2006). Effect of organic amendment and plant roots on the solubility and mobilization of lead in soils at a shooting range. *Journal of Environmental Quality* 35: 1026–1031.

Lewis, R.J. (1993). Hawley's condensed chemical dictionary. 12th ed. New York, NY: Van Nostrand Rheinhold Co.

Luo, C., Liu, C., Wang, Y., Liu, X., Li, F., Zhang, G. and Li, X. (2011). Heavy metal contamination in soils and vegetables near an e-waste processing site, South China. *Journal of Hazardous Materials* 186: 481–490.

Madisa, M.E., Assefa, Y. and Obopile, M. (2010). Assessment of production constraints, crop and pest management practices in peri-urban vegetable farms of Botswana. *Egypt Academic Journal of Biological Science* 1: 1–10.

Martin, S. and Griswold, P.G.W. (2009). Human health effects of heavy metals. Environmental Science and Technology Briefs for Citizens. Issue 15: 1–6.

Modaihsh, A.S., Al-Swailem, M.S. and Mahjoub, M.O. (2004). Heavy metals content of commercial inorganic fertilizers used in the Kingdom of Saudi Arabia. *Agricultural and Marine Sciences* 9: 21–25.

Nkegbe, E. (2005). Assessment of heavy metal compositions in Glen Valley dry sludge. *Journal of Applied Science* 5: 1399–1401.

Obopile, M., Munthali, D.C. and Matilo, B. (2008). Farmers' knowledge, perceptions and management of vegetable pests and diseases in Botswana. *Crop Protection* 27: 1220–1224.

Peijnenburg, W.J.G.M. and Jager, T. (2003). Monitoring approaches to assess bioaccessibility and bioavailability of metals: matrix issues. *Ecotoxicology and Environmental Safety* 56: 63–77.

Pule-Meulenberg, F. and Batisani, N.J. (2004). A review of Botswana soil fertility research: current status and prospects. *UNISWA Journal of Agriculture* 12: 60–67.

Pule-Meulenberg, F., Moganane, B.G. and Dikinya, O. (2005). Physicochemical properties of soil from five villages in Botswana with respect to soil degradation. *Caspian Journal of Environmental Sciences* 3: 29–34.

Rahman, H., Sabreen, S., Alam, S. and Kawai, S. (2005). Effects of nickel on growth and composition of metal micronutrients in barely plants grown in nutrient solution. *Journal of Plant Nutrition* 28: 393–404.

Ramadan, M.A.E. and Al-Ashkar, E.A. (2007). The effect of different fertilizers on the heavy metals in soil and tomato plant. *Australian Journal of Basic and Applied Sciences* 1: 300–306.

Reichman, S.M. (2002). The responses of plants to metal toxicity: a review focusing on copper, manganese, and zinc. Australian Minerals and Energy Environment Foundation, paper 4.

Ros, R., Cooke, D.T., Martinez-Cortina, C. and Picazo, L. (1992). Nickel and cadmium-related changes in growth, plasma membrane lipid composition, ATPase hydrolytic and proton-pumping of rice (*Oryza sativa* L.cv. Bahia) shoots. *Journal of Experimental Botany* 43: 1475–1481.

Sampanpanish, P. and Pongpaladisai, P. (2011). Effect of organic fertilizer on cadmium uptake by rice grown in contaminated soil. *International Conference on Environmental and Agricultural Engineering* 15: 103–109.

Schaecke, W., Tanneberg, H., Schilling, G. (2002). Behavior of heavy metals from sewage sludge in a Chernozem of the dry belt in Saxony-Anhalt/Germany. *Journal of Plant Nutrition and Soil Science* 165: 609–617.

Sharma, D.C., Sharma, C.P. and Tripathi, R.D. (2003). Phytotoxic lesions of chromium in maize. *Chemosphere* 51: 63–68.

Silveira, M.L.A., Alleoni, L.R.F., Casagrande, J.C. and Camargo, O.A. (2002). Copper adsorption in oxidic soils after removal of organic matter and iron oxides. *Communications in Soil Science and Plant Analysis* 33: 3581–3592.

Sklodowski, P., Maciejewska, A. and Kwiatkowska, J. (2006). The effect of organic matter from brown coal on bioavailability of heavy metals in contaminated soils. In: Twardowska, I., Allen, H.E., Haggblom, M.M. and Stefaniak, S. (eds) Soil and Water Pollution Monitoring, Protection and Remediation. pp. 299–307.

Strawn, D.G. and Sparks, D.L. (2000). Effects of soil organic matter on the kinetics and mechanisms of Pb (II) sorption and desorption in soil. *Soil Science of America Journal* 64: 144–156.

Ta'any, R.A., Ammari, T.G. and Jiries, A. (2013). Revegetation in arid zones: environmental impact of treated wastewater irrigation in Al-karak Province, Jordan. *Polish Journal of Environmental Studies* 22: 569–575.

Thomas, E.Y., Omueti, J. and Ogundayomi, O. (2012). The effect of phosphate fertilizer on heavy metal in soils and *Amaranthus caudatus*. *Agriculture and Biology Journal of North America* 3: 145–149.

Tu, C., Zheng, C. and Chen, H. (2001). Distribution of Copper and Zinc fractions in red soil as influenced by fertilizer application. *Communication in Soil Science and Plant Analysis* 32: 661–673.

UNFPA (2007). State of world population: unleashing the potential of urban growth. UNFPA. 108 pp.

UNEP (2008). Draft final review of scientific information on cadmium. UNEP Chemicals Branch, DTIE, 188 pp.

Ugbaje, S.U. and Agbenin, J.O. (2012). Suitability of urban wastes for crop production in Zaria, northern Nigeria: bioavailability and geochemical fractions of potentially toxic elements. *International Journal of Environmental Studies* 69: 121–133.

Wei, B. and Yang, L. (2010). A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. *Microchemical Journal* 94: 99–107.

Williams C.H. and David, D.J. (1973). The effect of superphosphate on the cadmium content of soils and plants. *Australian Journal of Soil Research* 11: 43–56.

Wu, F., Tseng, R. and Juang, R. (2010). A review and experimental verification of using chitosan and its derivatives as adsorbents for selected heavy metals. *Journal of Environmental Management* 91: 798–806.

Wu, L., Pan, X., Chen, L., Huang, Y., Teng, Y., Luo, Y. and Christie, P. (2013). Occurrence and distribution of heavy metals and tetracyclines in agricultural soils after typical land use change in east China. *Environmental Science Pollution Resources* 20: 8342–8354.

Yadav, S.K. (2010). Heavy metals toxicity in plants: an overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. *South African Journal of Botany* 76: 167–179.