Urban farming as a possible source of trace metals in human diets

AUTHORS:
Joshua O. Olowoyo[1]
Gladness N. Lion[1]

AFFILIATION:
[1]Department of Biology, Sefako Makgatho Health Sciences University, Pretoria, South Africa

CORRESPONDENCE TO:
Joshua Olowoyo

EMAIL:
woleolowoyo@yahoo.com

POSTAL ADDRESS:
Department of Biology, Sefako Makgatho Health Sciences University, PO Box 60, Medunsa 0204, South Africa

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Rapid industrialisation and urbanisation have greatly increased the concentrations of trace metals as pollutants in the urban environment. These pollutants (trace metals) are more likely to have an adverse effect on peri-urban agriculture which is now becoming a permanent feature of the landscape of many urban cities in the world. This review reports on the concentrations of trace metals in crops, including leafy vegetables harvested from different urban areas, thus highlighting the presence of trace metals in leafy vegetables. Various pathways of uptake of trace metals by leafy vegetables, such as the foliar and roots, and possible health risks associated with urban faming are discussed and various morphological and physiological impacts of trace metals in leafy vegetables are described. Defensive mechanisms and positive aspects of trace metals in plants are also highlighted.

Introduction

Urban farming can be defined as the act of cultivating food crops, mostly vegetables, wherever land is available around or in the immediate vicinity of a major city.[1,2] Farming activities around urban areas have become a prominent feature of some urban city landscapes, especially in developing countries.[3] There are several reasons for farming activities around peri-urban areas and these include easy access to markets and transportation of goods. In some countries, poor urban households use urban farming to increase their household income by selling the yield or surplus to reduce part of daily expenses.[4] The other probable reason for the increase in urban farming is the shortage of land. This involves farming areas previously used for either household or industrial waste,[5] supported by the notion that the soil will be very fertile. Urban farming also supports the campaign for organic farming. Consumers, in most cases, evaluate quality of leafy vegetables on their dark green colour and on size of the leaves as opposed to where farming activities have taken place.[6] However, in urban city centres where farming activities are carried out around industrial areas, safety around the consumption of these vegetables cannot be guaranteed because various disposal practices often cause the accumulation of potentially toxic trace elements in the soil.[7,8]

Anthropogenic activities such as mining, emissions from vehicles, wrong agricultural practices and improper waste disposal are major sources of trace metal pollution in the urban environment.[5,9] It was recently discovered that a large percentage of toxic trace metals find their way into the human diet through consumption of vegetables and agricultural products.[5-14]

In acceptable limits, trace metals play an important role in the health and physiological activities of plants, animals and humans.[15] They are required in minute quantities as natural components of the environment. For example, zinc is an essential element required in minute quantities in living organisms, but when supplied in high quantities, it can be toxic to plants, producing purplish-red coloured leaves which is a symptom associated with phosphorus deficiency. Zinc may also cause chlorosis in younger leaves which may extend to older leaves.[16] In humans, excess zinc may lead to metal poisoning and growth retardation. Excess nickel and lead may result in increased production of reactive oxygen species and membrane permeability disruption in plants. In all, concentrations of heavy metals above the required limits in plants are known to cause various deleterious effects on several plants systems such as the photosynthetic ability of the plants, mineral uptake and interactions with the water regime from the soil. In humans, excess lead may affect the functions of the liver and kidneys.[10,17,18]

The present review will establish, amongst others, the various pathways by which trace metals may be taken up by plants, the effects of trace metals on the morphology and physiology of the plants, the positive aspects of trace metals in plants and also the possible health risk for humans and livestock if trace metals are ingested in high concentrations.

Evidence of trace metals in plants

High deposition and accumulation of trace metals in the edible part of root and leafy crops has been reported in the literature.[19,20] Vegetables are capable of accumulating trace metals from polluted soil and also from surface deposition onto their shoots in polluted atmospheric environments.[14] Trace metals in the air have been reported to significantly influence total metal concentration of vegetable plants, especially when washing is not thoroughly done.[18]

Atmospheric fallout is one of the chief contributors to heavy metal uptake by plants through the stomata. The stomata openings are located on the surface of the plant leaves and perform multiple functions that include water regulation in the plant. Particulate matter from atmospheric fallout may be found deposited on the leaf surface and find a way into the leaves through the stomata. Smaller particles from atmospheric fallout may be incorporated into the leaves, whereas large agglomerates are trapped on the surface wax.[21,22] The extent of uptake and the pathways involved may depend on the plant species and on the metal involved.[23] The opening and closing of stomata may provide entrance for trace metals, blocking the stomata in some cases and may ultimately lead to the death of the plant.[23] Entrance of metals via the foliage parts of plants was noted to be one of the major pathways by which metals enter leaves in a polluted area.[24] Figures 1 and 2 indicate the presence of trace metals around the stomata.

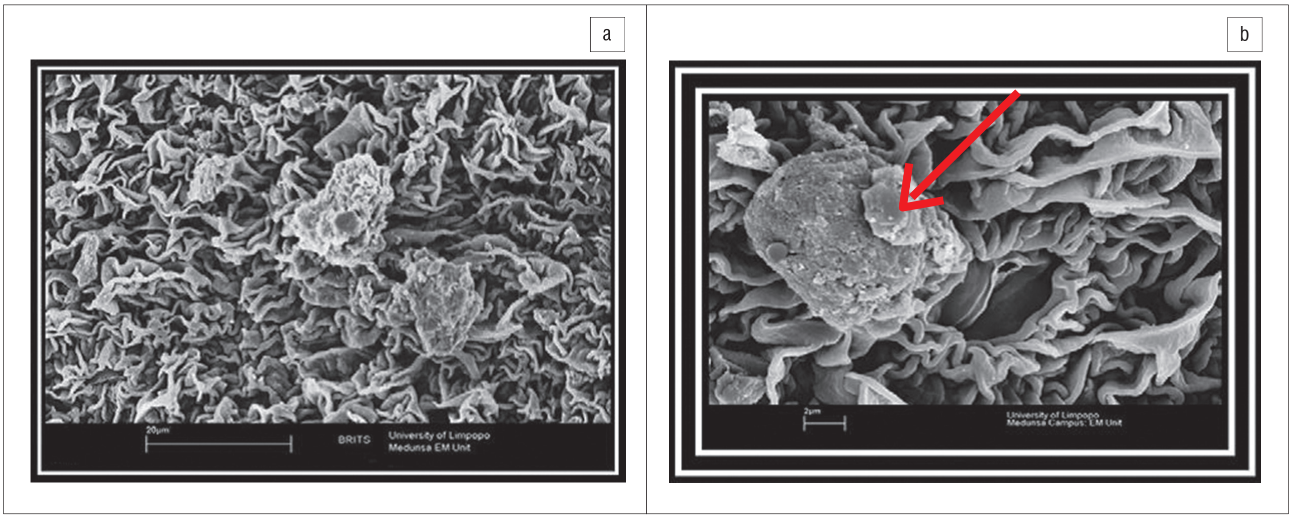

Figure 1: Presence of pollutants around the stomata of leaves collected for a study conducted in Pretoria, South Africa at (a) 2000X magnification and (b) 3000X magnification.[9] The stomata are the bean-shaped structures and the arrow is pointing to the pollutants around them.

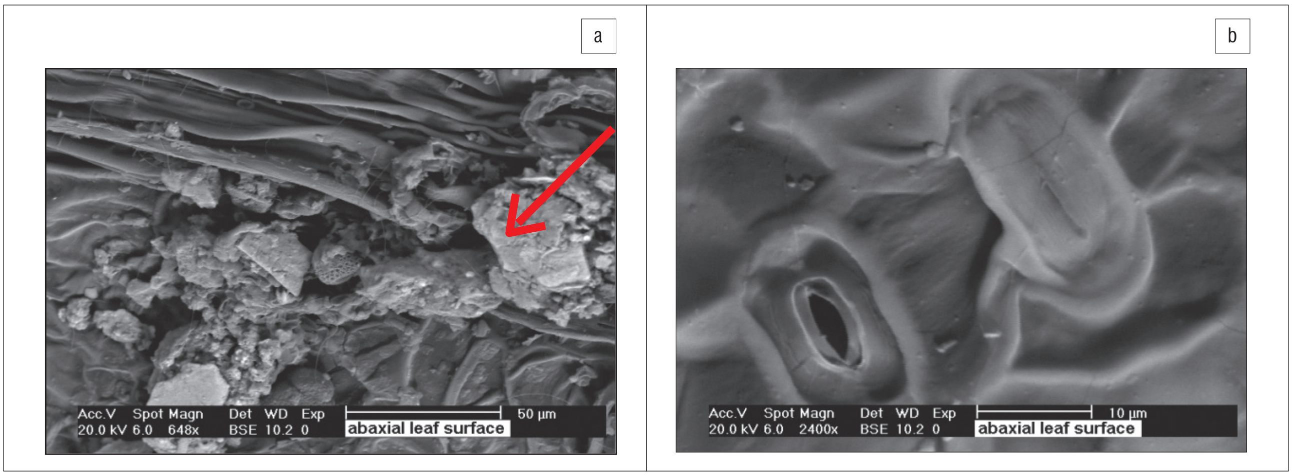

Figure 2: Presence of pollutants around the stomata of leaves collected for a study conducted in Belgrade, Serbia.[25] at (a) 648X magnification and (b) at 2400X magnification. The stomata are the bean-shaped structures and the arrow is pointing to pollutants around them.

In a separate study on lead uptake by lettuce leaves, it was discovered that particulate matter deposited on plant leaves may be retained by cuticular waxes and trichomes, while some of the metals contained in particulate matter can penetrate inside plant tissues.[26] Micro-X-ray fluorescence, scanning electron microscopy coupled with energy dispersive X-ray microanalysis, and time-of-flight secondary ion mass spectrometry were used to investigate the localisation and the speciation of lead in the leaves of different plants around a copper smelter company and it was found out that lead-enriched particulate matter was present on the surface of plant leaves.[24] The study further reported on biogeochemical transformations on the leaf surfaces with the formation of lead secondary species ($PbCO_3$ and organic lead).

Toxicity of trace metals in plants

The effect of trace metals on the epidermis was demonstrated on the young leaves of soyabean.[26,27] The young leaves did not show visual symptoms when exposed to cadmium ions and the authors observed that cadmium ions did not have any effect on the closing and opening of the stomata. However, findings have revealed that interactions of cadmium ions with K^+, Ca^{2+} and abscisic acid showed strong interference with the guard cells.[28,29] The application of cadmium on the leaf surfaces influenced the number of stomata, decreasing the number of stomata and stomatal openings on the leaf surface of the young leaves of soybeans.[27]

Several authors have also reported on the adverse effect of lead in plants. Lead toxicity is said to have a negative effect on biomass production in plants as it affects chlorophyll biosynthesis and photosynthesis.[30,31] Increased concentrations of lead may also inhibit or delay enzyme activity changes in membrane permeability and water disturbance in plants, which may affect the growth of the plant negatively.[32]

Cadmium may penetrate the root via cortical tissue and reach the xylem through either the apoplastic or symplastic pathways possibly resulting in cadmium toxicity in plants.[33,34] Soil pH is known to influence cadmium uptake and transportation. Uptake of cadmium by corn was lower in acid soils with high organic matter content. Cadmium has also been found co-accumulated with zinc in the aerial parts of *Arabidopsis halleri*.[35] Toxicity of nickel affected the seedlings of *Pisum sativum* by changing the potassium uptake and water content,[36] showing that higher concentrations of nickel may lead to a reduction in plant growth, leading to oxidative stress.

When leafy vegetables are properly washed, the concentrations of chromium and lead may be reduced. However, the exogenous contamination of leaves may not be reduced in some instances owing to the nature of the vegetables, as was in the case with *Gynandropsis gynandra* L. that showed a marked tendency to accumulate lead and chromium.[5] A similar observation was noted in a study by Gabrielli and Sanità di Toppi[37] where the dominant pathway for most trace elements to vegetable roots was from the soil, while trace elements in vegetable leaves appeared to originate mostly from the atmosphere. The result further indicated that high accumulation of trace metals such as lead, cadmium and chromium were the result of atmospheric deposition.

In all, it was evident that trace metals could reach the edible parts of vegetables, especially the leafy parts, through atmospheric deposition and could also be translocated to various parts of the plants via the root system.

Trace metals uptake mechanism by plants

The process of uptake, translocation and bioaccumulation of trace metals in plants could be influenced by a number of factors such as climate, atmospheric deposition, the concentration of trace metals in soil, the nature of the soil in which plants are grown (soil pH, soil organic matter content and soil texture), the degree of maturity of the plants at the time of harvest and the type of trace metals.[15,37-39] Among crop types, leafy vegetables such as lettuce and cabbage have the greatest ability to take up trace elements from the soil.[40] The mobility of trace metals in soil is favoured mostly under acidic conditions. Treating soil with lime in order to reduce soil acidity reduces the bioavailability of trace metals.[41,42] Therefore, low pH levels are effective in the remediation of polluted soil, while the soil organic matter ensures the availability of trace metals to the plant.[42] On the other hand, at high levels of soil pH, the formation of soluble organometallic complexes may increase metal solubility although this is not true for calcareous soil.[43]

An increase in the amount of soil organic matter helps plants minimise trace metal absorption.[44] The introduction of organic matter amendments in conjunction with lime had been used to assist in immobilising trace metals.[45] However, the effects of organic matter on the bioavailability of trace metals in soil depend on the nature of the organic matter, microbial degradability, salt content, soil type and the particular heavy metal.[46] In most cases, metallic elements are actively retained by lands that are rich in organic matter. The retention of trace metals in the soil affects the mobility of these elements and interferes with the uptake process. The bioavailability of trace metals is much lower in the presence of manure when compared to humified compost, suggesting that different types of organic matter may affect mobility of trace metals differently.[47] This may be as a result of the ability of the matter used to redistribute trace metals from soluble and exchangeable forms to fractions associated with organic matter or carbonates and the residual fraction.[48]

In the root area where the plant interacts with the soil, metal ions cannot move freely across the cellular membranes. The membrane structure of the plant root is lipophilic, which requires that the transport be facilitated by proteins with transport functions.[49,50] In the rhizosphere, metal transport is carried out by two processes known as bulk flow and diffusion.[51,52] This process of uptake by plants is soon followed by a process controlled by root pressure and leaf evaporation, called transpiration. Through transpiration, the plant is able to absorb the trace metals through the roots via the xylem to the shoot of the plant. The process is dependent on water demand by the leaves in the aerial part of the plant.[49]

Uptake of trace metals by higher or vascular plants is often through the root system, but can also occur through the leaves. It may therefore be difficult to distinguish whether the metals found in the plant tissues were originally from the air or soil.[53] Plants that are tolerant to high levels of trace metals (also called hyperaccumulators) have the capacity to remove contaminants from the soil. One example of such a plant is *Thlaspi caerulescens* that has been used for phytoremediation of soils, especially in areas previously polluted by mining activities.[41] The mechanism for hyperaccumulation remains unclear though it is generally believed to invlove three major phases involving rapid uptake of metals by the roots, high rate of translocation from roots to shoots and high storage capacity by vascular compartmentalisation.[41]

Metal uptake by plants is affected by metal solubility and availability in the soil. In a situation where the level of trace metals in soil is very high, the release of root exudates and acidification are common mechanisms that are used by plants to modify the root area to acquire nutrients from the soil.[41,49] In the case of nutrient movement across the biological membrane, plants have developed a specific mechanism meditated by proteins, for uptake, translocation and storage of the nutrients.[42,49] Membrane transporters are equipped with a structure that binds ions before transportation. This structure is receptive only to certain ions and as such is specific in their mode of action[49,54] The transmembrane structure then facilitates the transfer of bound ions from extracellular space through the hydrophobic environment of the membrane into the cell. Despite the presence of this structure, only a fraction of the total amount of ions associated with the roots are finally absorbed into plant cells.[54] The other form of metal uptake in plants, apart from binding to the cell wall, is sequestration in cellular structures such as the vacuole, though this may make the heavy metals unavailable for translocation to the shoot.[55]

The evaporation of water from the leaves may also affect plant uptake and accumulation of trace metals. The evaporation process serves as a pump for more nutrients and other substances to be absorbed into plant roots. This process, called evapotranspiration, moves water and contaminants into the plants.[42] The accumulation of metal contaminants is mostly assisted by microorganisms, fungi and bacteria that live in the root area. These microorganisms in the rhizosphere and closely associated plants may contribute to the mobility of metal ions. At the same time, plant roots release nutrients that sustain a rich microbial community in the root area, thus establishing an important symbiotic relationship between soil microorganisms and plants.[42,49] In order to facilitate the transport process, several families of proteins are involved namely (1) influx transporter families such as zinc, a regulated transporter, iron, a regulated transporter protein, yellow-stripe and natural resistance associated macrophage protein and (2) efflux protein families such as cation exchanger, ATB-binding cassette and cation diffusion facilitator.[42,56] Because these proteins are substrate specific, the comparison between influx and efflux transporters revealed that efflux proteins export metals from the cytoplasm while influx proteins take up proteins from the soil or medium.[56]

Depending on their ability to adapt and reproduce in soils heavily contaminated with trace metals, higher plant species can be divided into two main groups. The two groups are the pseudometallophytes (plants that grow on both contaminated and non-contaminated soil) and absolute metallophytes (plants that grow only on metal contaminated and naturally metal-rich soils).[57] The use of *Raphanus sativus* (a pseudometallophyte) for example, demonstrated the potential for root uptake in lead contaminated soil.[58] Baker[58] showed that radish is a hyperaccumulator plant that can concentrate trace metals in different plant parts. It was also demonstrated that radishes are effective for remediation of polluted soil through their potential to extract metals from soil up to a certain level of concentration.[58] The ability of plants to accumulate metals, thereby remediating metals, is directly proportional to the presence or availability of microorganisms in that plant's rhizosphere.[59] In the study it was explained that microbial communities such as fungi, bacteria and other microbes are capable of altering the soil environment and as a result will translocate, absorb or sequester contaminants such as trace metals.[59,60]

Over the years, more than 400 plant species with the ability to take up high levels of heavy metals in soil and water have been identified. *Thlapsi* spp., *Brassica spp*., *Sedum affredii* and *Arabidopsis* spp.*,* among others, were studied.[61,62] The use of vegetable plants has also been demonstrated by some researchers.[63] For example, *Amaranthus dubius,* also known as *morogo* or wild spinach in South Africa, was found to have the ability to take up and translocate metals such as chromium, mercury, arsenic, lead, copper and nickel to the aerial parts of the plant.[64] Some medicinal plants such as *Datura stramonium* and *Amaranthus spinosus* are capable of accumulating some trace metals in their tissues.[60]

It is believed that trace metals can help plants protect themselves from diseases and biological stress.[65,66] If a metal becomes more toxic to a pathogen than to the plant, the metal can hamper the virulence of the pathogen and can increase the resistance of the plant to the biotic stress[65] by suffocating the pathogen in the plant. The excess trace metals found in the plant after the pathogen has been suffocated will then be redirected to normal growth.

The production of high levels of reactive oxygen species can adversely affect the plant. Therefore, plants have developed a defensive mechanism that involves glutathione in the detoxification of reactive oxygen species through the ascorbate–glutathione cycle.[67] During exposure to high levels of trace metals, accumulated metal ions are detoxified by phytochelatins that are produced from glutathione in the plant. These metal ions are then bound to phytochelatins to form complex structures that are sequestered or compartmentalised in the vacuole.[49,67]

Exposure to trace elements such as mercury, cadmium, lead and nickel in the soil, encourages the plants to formulate steps to counteract the effects of these toxins. Defensive mechanisms largely prevent the metals from getting inside the cells, but for metals that find a way into plants cells, they are neutralised and sequestered.[68]

Quantifying human risk associated with trace metals in plants

In a bid to quantify the likely health hazard associated with vegetables that are high in concentrations of trace metals, the target hazard quotient method (THQ) was developed and has been used by several authors.[69,70-72] Human health risks associated with these metals can be assessed based on the THQ method,[41] which takes into account the concentration of trace metals in food, the frequency of exposure, and the individual's age, body weight and frequency of consumption of the contaminated food. Should the THQ calculated for both adults and children exceed 1 (THQ>1) then a potential risk to the consumer will be suspected.[5,14,41] Mercury was recorded as the major health risk contributor in children and chromium as the least contributor. The method for calculating the THQ is:

$$HQM = ADDM / RfDM, \quad \text{Equation 1}$$

where $ADDM = (DI \times MFveg) / WB$.[14]

ADDM is the average daily dose (mg.kg/day) of the metal and RfDM is the reference dose (mg.kg/day). RfDM is defined as the maximum tolerable daily intake of a specific metal that has no adverse effect.[73] DI is the daily intake of leafy vegetables (kg/day), MFveg denotes the trace metal concentration in the vegetable tissues (mg/kg) and WB represents the body weight of investigated individuals. The DI is usually calculated at 0.182 kg/day for adults and 0.118 kg/day for children.[14,74] The body weight of investigated adults is assumed to be 55.7 kg and for children 14.2 kg.[3,14] If the value of HQM calculated should exceed 1 (HQM>1), then there may be potential risk to the consumer.

Conclusion

Trace metals are known for high mobility and bioavailability in consumed food products such as vegetables. Studies have shown that trace metals may find their way into the human system via the consumption of contaminated food crops harvested from polluted soil. The urban environment is constantly witnessing an increase in various developmental projects, with special reference to developing countries. If not properly managed, these projects may introduce contaminants, with special reference to trace metals, into the environment. However, farming activities are continuously been practised both on a small scale and a large scale around major cities and hence may be affected negatively by these contaminants.[71,75] Reports from the literature have suggested that leafy vegetables are capable of accumulating and storing these trace metals in their edible parts. There may be a serious problem associated with urban agriculture relating to balancing demands associated with increasing populations against potential hazards arising from the use of contaminated urban sites for food production. It is necessary to investigate and document the ability and uptake mechanism of most vegetables in order to identify and document those that can grow without accumulating trace metals in order to reduce the danger trace metals might pose to consumers. It is also important to develop new farming practices around urban city centres that will reduce or elucidate the availability and uptake of trace metals by plants.

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Authors' contributions

G.N.L. was responsible for the study under the supervision of J.O.O.

References

1. Egziabher AG, Lee-Smith D, Maxwell DG, Memon PA, Mougeot L, Sawio C. Cities feeding people: An examination of urban agriculture in east Africa. Ottawa: International Development Research Centre; 1994.
2. Foeken D. To subsidise my income, urban farming in an east-African town. African Student Centre Series. Leiden: Brill; 2006.
3. World Health Organization (WHO). Report of the 32nd session of the Codex Committee on food additives and contaminants, ALINORM 01/12; 2000 March 20–24; Beijing, China. Geneva: WHO; 2001.
4. Vermeiren K, Adiyia B, Loopmans M, Tumwine FR, Van Rompaey A. Will urban farming survive the growth of African cities: A case study in Kampala (Uganda)? Land Use Pollut. 2013;35:40–49. http://dx.doi.org/10.1016/j.landusepol.2013.04.012
5. Nabulo G, Black CR, Craigon J, Young SD. Does consumption of leafy vegetables grown in peri-urban agriculture pose a risk to human health? Environ Pollut. 2012;23:389–398. http://dx.doi.org/10.1016/j.envpol.2011.11.040
6. Mapanda F, Mangwayana EN, Nyamangara J, Giller KE. Uptake of heavy metals by vegetables irrigated using wastewater and the subsequent risks in Harare, Zimbabwe. Phys Chem Earth ABC. 2007;32(15–18):1399–1405. http://dx.doi.org/10.1016/j.pce.2007.07.046
7. Ho, YB, Tai KM. Elevated levels of lead and other metals in roadside soils and grass and their use to monitor aerial metal depositions in Hong Kong. Environ Pollut J. 1988;49:37–51. http://dx.doi.org/10.1016/0269-7491(88)90012-7
8. Garcia R, Milan E. Assessment of Cd, Pb and Zn in roadside soils and grasses from Gipuzkoa (Spain). Chemosphere. 1998;37(8):1615–1625. http://dx.doi.org/10.1016/S0045-6535(98)00152-0
9. Olowoyo JO, Van Heerden E, Fischer JL, Baker C. Trace metals in soil and leaves of *Jacaranda mimosifolia* in Tshwane area, South Africa. Atmos Environ. 2010;44:1826–1830. http://dx.doi.org/10.1016/j.atmosenv.2010.01.048
10. Caggiano R, Sabia S, D'Emilio M, Macchiato M, Anastasio A, Ragosta M. Metal levels in fodder, milk, dairy products, and tissues sampled in ovine farms of southern Italy. Environ Res Lett. 2005;99:48–57. http://dx.doi.org/10.1016/j.envres.2004.11.002
11. Gonzalez-Miqueo L, Elustondo D, Lasheras E, Santamaria JM. Use of native mosses as biomonitors of heavy metals and nitrogen deposition in the surroundings of two steel works. Chemosphere. 2010;78:965–971. http://dx.doi.org/10.1016/j.chemosphere.2009.12.028
12. Honour SL, Bell JNB, Ashenden TWA, Cape JN, Power SA. Responses of herbaceous plants to urban air pollution: Effects on growth, phenology and leaf surface characteristics. Environ Pollut. 2009;157:1279–1286. http://dx.doi.org/10.1016/j.envpol.2008.11.049
13. Tomasevic M, Vukmirovic Z, Rajsic S, Tasic M, Stevanovic B. Characterization of trace metal particles deposited on some deciduous tree leaves in an urban area. Chemosphere. 2005;61:753–760. http://dx.doi.org/10.1016/j.chemosphere.2005.03.077
14. Nabulo G, Black CR, Young SD. Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. Sci Total Environ. 2010;408:5338–5351. http://dx.doi.org/10.1016/j.scitotenv.2010.06.034
15. Sharma RK, Agrawal M, Marshall F. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotox Environ Safe. 2007;66:256–288. http://dx.doi.org/10.1016/j.ecoenv.2005.11.007
16. Lee CW, Choi JM, Park CH. Micronutrient toxicity in seed geranium. J Am Soc Hort Sci. 1996;121(1):77–82.
17. Ali H, Khan E, Sajad MA. Phytoremediation of heavy metals – concepts and applications. Chemosphere. 2013;91:869–881. http://dx.doi.org/10.1016/j.chemosphere.2013.01.075

18. Li J, Li F, Liu Q. Spatial distribution and sources of dissolved trace metals in surface water of the Wei River, China. Water Sci Technol. 2013;67(4):817–823. http://dx.doi.org/10.2166/wst.2012.608

19. Lehoczky E, Szabo L, Horvath S, Marth P, Szabados I. Cadmium uptake by lettuce in different soils. Soil Sci Plant Anal. 1998;28:1903–1912. http://dx.doi.org/10.1080/00103629809370080

20. Sharma RK, Agrawal M, Marshall F. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotox Environ Safe. 2007;66:256–288. http://dx.doi.org/10.1016/j.ecoenv.2005.11.007

21. Nwoko CO, Mgbeahuruike L. Heavy metal contamination of ready-to-use herbal remedies in South Eastern Nigeria. Pak J Nutr. 2011;10:959–964. http://dx.doi.org/10.3923/pjn.2011.959.964

22. Birbaum K, Brogiolo R, Schellenberg M, Martinoia E, Stark WJ, Günther D. No evidence for cerium dioxide nanoparticle translocation in maize plants. Environ Sci Technol. 2010;44:8718–8723. http://dx.doi.org/10.1021/es101685f

23. Schreck E, Foucault Y, Geret F, Pradere P, Dumat C. Influence of soil ageing on bioavailability and ecotoxicity of lead carried by process waste metallic ultrafine particles. Chemosphere. 2011;85:1555–1562. http://dx.doi.org/10.1016/j.chemosphere.2011.07.059

24. Olivia SR, Espinosa EJF. Monitoring of heavy metals in topsoils, atmospheric particles and plant leaves to identify possible contamination sources. Microchem J. 2010;86:131–139. http://dx.doi.org/10.1016/j.microc.2007.01.003

25. Tomasevic M, Anicic M. Trace element content in urban tree leaves and SEM-EDAX characterisation of deposited particles. Facta Universitatis Series: Phys Chem Technol. 2010;8:1–13.

26. Uzu G, Sobanska S, Sarret G, Muñoz M, Dumat C. Foliar lead uptake by lettuce exposed to atmospheric fallouts. Environ Sci Techol. 2010;44:1036–1042. http://dx.doi.org/10.1021/es902190u

27. Debroviczka T, Pirselova B, Matusikova I. The effect of cadmium on epidermis of leaves of two soybean varieties. In: Proceedings of the 13th International Scientific Conference of PhD Students, Young Scientists and Pedagogues. 2012 Sep 19–20; Nitra, Slovak Republic. Available from: http://conferences.ukf.sk/index.php/phdconf/phdconf2012/paper/view/908

28. Barcelo J, Poschenrieder CH. Plant water relations as affected by heavy metal stress: A review. J Plant Nutr. 1990;13:1–37. http://dx.doi.org/10.1080/01904169009364057

29. Perfus-Barbeoch L, Leonhardt N, Vavasseur A, Forestier C. Heavy metal toxicity: Cadmium permeates through calcium channels and disturbs the plant water status. Plant J. 2002;32:539–548. http://dx.doi.org/10.1046/j.1365-313X.2002.01442.x

30. Cenki Tok B, Chabaux F, Lemarchand D, Schmitt A-D, Pierret M-C, Viville D, et al. The impact of water-rock interaction and vegetation on calcium isotope fractionation in soil- and stream waters of a small forested catchment (the Strengbach case). Geochim Cosmochim Acta. 2009;73:2215–2228. http://dx.doi.org/10.1016/j.gca.2009.01.023

31. Viville MC, Bagard D, Stille ML. The impact of vegetation on REE fractionation in stream waters of a small forested catchment (the Strengbach case). Geochim Cosmochim Acta. 2006;70:3217–3230. http://dx.doi.org/10.1016/j.gca.2009.01.023

32. Zhang WF, Liu XP, Cheng HF, Zeng EY, Hu YN. Heavy metal pollution in sediments of a typical mariculture zone in South China. Marine Poll Bull. 2012;64:712–720. http://dx.doi.org/10.1016/j.marpolbul.2012.01.042

33. Sharma P, Dubey RS. Lead toxicity in plants. Braz J Plant Physiol. 2005;17:35–52. http://dx.doi.org/10.1590/S1677-04202005000100004

34. Salt DE, Prince RC, Pickering IJ, Raskin I. Mechanism of cadmium mobility and accumulation in Indian mustard. Plant Physiol. 1998:109:1427–1433.

35. Yang YY, Jung JY, Song WY, Suh HS, Lee Y. Identification of rice varieties with high tolerance or sensitivity to lead and characterization of the mechanism of tolerance. Plant Physiol. 2000;124:1019–1026. http://dx.doi.org/10.1104/pp.124.3.1019

36. Srivastava PK, Gupta M, Mukherjee S. Mapping spatial distribution of pollutants in groundwater of a tropical area of India using remote sensing and GIS. Appl Geom. 2012;4(1):21–32. http://dx.doi.org/10.1007/s12518-011-0072-y

37. Gabrielli R, Sanità di Toppi L. Response to cadmium in higher plants. Environ Exp Bot. 1999;41:105–130. http://dx.doi.org/10.1016/S0098-8472(98)00058-6

38. Voutsa D, Grimanis A, Samara C. Trace elements in vegetables grown in industrial areas in relation to soil and air particulate matter. Environ Pollut. 1996;94:325–335 http://dx.doi.org/10.1016/S0269-7491(96)00088-7

39. Lake DL, Kirk PWW, Lester JN. The fractionation characterization and speciation of heavy metals in sewage sludge and sewage amended soils. J Environ Qual. 1984:13:175–183. http://dx.doi.org/10.2134/jeq1984.00472425001300020001x

40. Scott D, Keoghan JM, Allen BE. Native and low input grasses – A New Zealand high country perspective. New Zeal J Agr Res. 1996;39:499–512. http://dx.doi.org/10.1080/00288233.1996.9513211

41. Chaney RL, Malik M, Li YM, Brown SL, Angle JS, Baker AJM. Phytoremediation of soil metals. Curr Opin Biotech.1997;8:279–284. http://dx.doi.org/10.1016/S958-1669(97)80004-3

42. Wang W, Anderson BT, Phillips N, Kaufmann RK, Potter C, Myneni RB. Feedbacks of vegetation on summertime climate variability over the North American Grasslands. Part I: Statistical analysis. Earth Interact. 2006;10:1–27. http://dx.doi.org/10.1175/EI196.1

43. Tangahu BV, Abdullah SRS, Basri H, Idris M, Anuar N, Mukhlisin M. A review on heavy metals (As, Pb and Hg) uptake by plants through phytoremediation. Int J Chem Eng. 2011;2011, Art. #939161, 31 pages. http://dx.doi.org/10.1155/2011/939161.

44. Gregson SK, Alloway BJ. Gel permeation chromatography studies on the speciation of lead in solutions of heavily polluted soils. J Soil Sci. 1984;35:55–61.

45. Fijalkowski K, Kacprzac M, Grobelak A, Placek A. The influence of selected soil parameters on the mobility of heavy metals in soils. Inz I Ochr Srodo. 2012;15:81–92.

46. Clemente EP, Schaefer CEGR, Novais RF, Viana JH, Barros NF. Soil compaction around *Eucalyptus grandis* roots: A micromorphological study. Soil Res. 2005;43:139–146. http://dx.doi.org/10.1071/SR04069

47. Clemente R, Walker DJ, Roig A, Bernal MP. Heavy metal bioavailability in a soil affected by mineral sulphides contamination following the mine spillage at Aznalcollar (Spain). Biodegradation. 2003;14:199–205. http://dx.doi.org/10.1023/A:1024288505979

48. Walker TR, Young SD, Crittenden PD, Zhang H. Anthropogenic metal enrichment of snow and soil in north-eastern European Russia. Environ Pollut. 2003;121:11–21. http://dx.doi.org/10.1016/S0269-7491(02)00212-9

49. Schulman LJ, Sargent EV, Naumann BD, Faria EC, Dolan DG, Wargo JP. A human health risk assessment of pharmaceuticals in the aquatic environment. Hum Ecol Risk Assess. 2002;8(4):657–680. http://dx.doi.org/10.1080/10807030290879899

50. Lasat MM. The use of plants for the removal of toxic metals from contaminated soil. Washington, DC: American Association for the Advancement of Environmental Science and Engineering; 2012. p. 1–33.

51. Jung MC. Heavy metal contamination in soils and factors affecting metal uptake by plants in the vicinity of a Korean Cu-W mine. Sensors. 2008;8:2413–2423. http://dx.doi.org/10.3390/s8042413

52. Corey RB, King LD, Lue-Hing C, Fanning DS, Street JJ, Walker JM. Effects of sludge properties on accumulation of trace elements by crops. In: Page AL, Logan TJ, Ryan JA, editors. Land application of sludge, food chain implications. Chelsea: Lewis Publications; 1987.

53. Barber SA. Soil nutrient bioavailability: A mechanistic approach. New York: John Wiley; 1984.

54. Tomašević M, Aničić M. Trace element content in urban tree leaves and SEM-EDAX characterization of deposited particles. Facta Universitatis Series: Phys Chem Technol. 2010;8(1):1–13.

55. Yadav SK. Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. S Afr J Bot. 2010;76:167–179. http://dx.doi.org/10.1016/j.sajb.2009.10.007

56. Lasat MM, Fuhrmann M, Ebbs SD, Cornish JE, Kochvian LV. Phytoremediation of a radiocesium-contaminated soil: Evaluation of cesium-137 bioaccumulation in the shoots of three plant species. J Environ Qual. 1998;27:165–169. http://dx.doi.org/10.2134/jeq1998.271165x

57. Verkleij JAC, Golan-Goldhirsh A, Antosiewicz DM, Schwitzguebel J, Schroder P. Dualities in plant tolerance to pollutants and their uptake and translocation to the upper plant parts. Environ Exp Bot. 2009;67(1):10–22. http://dx.doi.org/10.1016/j.envexpbot.2009.05.009

58. Baker AJM. Meta tolerance. New Phytol. 1987;106:93–111. http://dx.doi.org/10.1111/j.1469-8137.1987.tb04685.x

59. Hamadouche NA, Aoumeur H, Djediai S, Slimani M, Aoues A. Phytoremediation potential of *Raphanus sativus* L. for lead contaminated soil. Act Biol Szeg. 2012;56(1):43–49.

60. Krumins JA, Long ZT, Steiner CF, Morin PJ. Indirect effects of food web diversity and productivity on bacterial community function and composition. Funct Ecol. 2006;20:514–521. http://dx.doi.org/10.1111/j.1365-2435.2006.01117.x

61. Frey B, Stemmer M, Widmer F, Luster J, Sperisen C. Microbial activity and community structure of a soil after heavy metal contamination in a model forest ecosystem. Soil Biol Biochem. 2006;38:1745–1756. http://dx.doi.org/10.1016/j.soilbio.2005.11.032

62. Dahmani-Muller H, Oort FV, Denaix L. Is metal extraction by *Arabidopsis halleri* related to exchangeable metal rates in soils amended with different metal-bearing solids? Environ Pollut. 2002;117(3):487–498. http://dx.doi.org/10.1016/S0269-7491(01)00180-4

63. Lone MI, He ZL, Stoffella PJ, Yang XE. Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives. J Zhejiang Univ-Sc B. 2008;9:210–220. http://dx.doi.org/10.1631/jzus.B0710633

64. Mellem JJ, Baijnath H, Odhav B. Bioaccumulation of Cr, Hg, As, Pb, Cu and Ni with the ability for hyperaccumulation by *Amaranthus dubius.* Afr J Agric Res. 2008;7:591–596.

65. Olowoyo JO, Okedeyi NM, Mkolo NM, Lion GN, Mdakane STR. Uptake and translocation of heavy metals by medicinal plants growing around a waste dump site in Pretoria, South Africa. S Afr J Bot. 2011;78:116–121. http://dx.doi.org/10.1016/j.sajb.2011.05.010

66. Poschenrieder C, Tolra R, Barcelo J. Can metals defend plants against biotic stress? Trends Plant Sci. 2006;11:288–295. http://dx.doi.org/10.1016/j.tplants.2006.04.007

67. Miteva E, Hristova D, Nenova V, Manava S. Arsenic as a factor affecting virus infection in tomato plants; changes in plant growth, peroxidase activity and chloroplast pigments. Sci Hortic-Amsterdam. 2005;105:343–358. http://dx.doi.org/10.1016/j.scienta.2005.01.026

68. Yadav SK. Heavy metal toxicity in plants. An overview of the role of gluthathione and phytochelatins in heavy metals stress tolerance of plants. S Afr J Bot. 2010;76:167–179. http://dx.doi.org/10.1016/j.sajb.2009.10.007

69. Hu H. Human health and heavy metal exposure. In: McCally M, editor. Life support. The environment and human health. Cambridge, MA: Massachusetts Institute of Technology Press; 2012. p. 1–12.

70. Shen L, Xia B, Dai X. Residues of persistent organic pollutants in frequently-consumed vegetables and assessment of human health risk based on consumption of vegetables in Huizhou, South China. Chemosphere. 2013;93:2254–2263. http://dx.doi.org/10.1016/j.chemosphere.2013.07.079

71. Xu D, Zhou P, Zhan J, Gao Y, Dou C, Sun Q. Assessment of trace metal bioavailability in garden soils and health risks via consumption of vegetables in the vicinity of Tongling mining area, China. Ecotox Environ Safe. 2013;90:103–111. http://dx.doi.org/10.1016/j.ecoenv.2012.12.018

72. Olowoyo JO, Lion GN. Uptake and translocation of trace metals from soil collected around waste dump sites and a mining area by vegetables [MSc dissertation]. Pretoria: University of Limpopo; 2013.

73. Martin S, Griswold W. Human health effects of heavy metals. Environ Sci Technol Briefs Citizens. 2009;15:1–6.

74. Mahmood A, Malik RN. Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. Arab J Chem. 2014;7:91–99. http://dx.doi.org/10.1016/j.arabjc.2013.07.002

75. Lei M, Yue QL, Chen TB, Huang ZC, Liao XY, Liu YR, et al. Heavy metal concentrations in soils and plants around Shizhuyuan mining area of Hunan Province. Acta Ecol Sin. 2005;25(5):1146–1151. In Chinese with English abstract.