Journal of Applied Life Sciences and Environment
https://jurnalalse.com

Case Study
https://doi.org/10.46909/alse-554078
Vol. 55, Issue 4 (192) / 2022: 495-504

THE PHYTOREMEDIATION POTENTIAL OF *Lavandula angustifolia* Mill. GROWN IN SOILS HISTORICALLY POLLUTED WITH HEAVY METALS: A CASE STUDY FROM BAIA MARE, ROMANIA

Roxana VIDICAN[a], Tania MIHĂIESCU[b], Anca PLEȘA[a,*], Anamaria MĂLINAȘ[a] and Bianca POP[a]

[a]Department of Plant Culture, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine, Calea Mănăștur 3-5, Cluj-Napoca 400372, Romania; e-mail: roxana.vidican@usamvcluj.ro; anamaria.malinas@usamvcluj.ro; bianca-alexandra.pop@student.usamvcluj.ro
[b]Department of Environmental Engineering and Protection, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine, Calea Mănăștur 3-5, Cluj-Napoca 400372, Romania; e-mail: tania.mihaiescu@usamvcluj.ro

*Correspondence: anca.plesa@usamvcluj.ro

Received: Nov. 28, 2022. Revised: May 04, 2023. Accepted: May 04, 2023. Published online: May 12, 2023

ABSTRACT. The aim of this research is to evaluate the ability of *Lavandula angustifolia* Mill. (LA) to accumulate and translocate heavy metals (HMs) from disturbed soils. The study was conducted on a site historically polluted with HMs, located in Baia Mare, Romania. Soil samples and underground (root) and aboveground parts of plants (leaves and stems) were collected from the study site and analysed for HM content (Pb, Cu, Cd, and Zn) by XRF spectroscopy. The potential for phytoremediation of lavender was evaluated according to the bioconcentration (BCF) and the translocation (TF) factors. The results showed that LA efficiently accumulated Cd and Zn. A different partitioning of HM among plant tissues was observed, showing the highest content in the aboveground mass compared to that found in the root (except for Zn). The TF ranged between 0.62 and 3.59, with values higher than unity for Cd and Pb, revealing that this plant is a suitable candidate for phytoextraction of these two trace elements. According to the BCF values, it seems that lavender is able to bioaccumulate high amounts of Cd (6.66), Pb (1.09), and Zn (2.87). Although more research is necessary for conclusive results, our findings confirm the ability of *Lavandula angustifolia* Mill. to tolerate, accumulate, and translocate high levels of HMs from soil to the aerial parts of the plant.

Keywords: phytoremediation; lavender; heavy metals; bioconcentration and translocation factors.

INTRODUCTION

Heavy metal (HM) soil pollution is now a significant and pervasive environmental issue, particularly in urban areas (Zwolak *et al.*, 2019; Yang-Guang *et al.*, 2016; Gupta *et al.*, 2013), affecting living organisms and the quality of soil, water, and air. These types of polluted sites are generally referred to as post-industrial brownfields, defined as industrial properties that remain abandoned or underutilised in part because of HM contamination (Zhang Yi, 2012). Given the current need for green spaces in urban landscapes, the value of brownfields as potential recreational spaces is currently being increasingly recognised (Merwin *et al.*, 2022). When it comes to cleaning up soils contaminated with HM, several methods are currently available. Among these, the phytoremediation technique is regarded as the most eco-friendly and economical technology. This emerging technique is based on the potential of some green plants to remove HMs from contaminated soils (Angelova *et al.*, 2015; Carabulea *et al.*, 2022). These plant species have developed specific mechanisms which allow them to adsorb, transport, and translocate HMs among plant tissues through several natural, biophysical, and biochemical processes (Meagher, 2000). Modern phytoremediation technologies include phytostabilisation, phytodegradation, phytovolatilisation, and phytoextraction. Phytostabilisation involves the reduction of mobility and bioavailability of contaminants in the soil, either by physical or chemical effects, aiming to prevent their further dispersal (Greipsson, 2011; Lamine and Saunders, 2022). In phytodegradation, a process applied generally to organic compounds, the contaminants are decomposed or converted into less toxic forms through the release of enzymes from roots or metabolic activities within plant tissues (Greipsson, 2011; Liu *et al.*, 2020). In phytovolatilisation, the contaminants are absorbed by plant roots, converted to a gaseous state, and volatilised into the atmosphere by the foliar system through the evapotranspiration process (Laghlim *et al.*, 2015). Phytoextraction refers to the accumulation of contaminants in the aboveground (harvestable) biomass, either during a continuous process (using hyperaccumulator plants), or an induced process (using chelating agents). Hyperaccumulator plants are adapted to naturally occurring, metalliferous soils and have the ability to hyperaccumulate various metals (Greipsson, 2011). Laghlimi *et al.* (2015) listed ten of the most significant criteria for the selection of plant species suitable for phytoextraction: (1) plant species tolerance to high metal concentrations, (2) high metal-accumulating capacity, (3) rapid growth rate, (4) accumulation of trace elements in the above-ground parts, (4) easy of harvest, (5) extended root system for exploring large soil volumes, (6) high translocation factor, (7) simple agricultural management, (8) good adaptation to current prevailing environmental and climatic conditions, (9) resistance to pathogens and pests, (10) repulse herbivores.

Finding the best plant species candidates is the fundamental issue with phytoremediation, given that potentially hazardous HMs metals can enter the bodies of humans and other animals through food chains. (Gupta *et al*., 2013). Because numerous studies have established that the essential oils are free from the risk of heavy metals, using them in place of food crops could therefore offer a promising alternative and could be processed further for their specific uses (Khajanchi *et al*., 2013). One such example is *Lavandula angustifolia* Mill. (lavender), an aromatic plant used in folk medicine (Caputo *et al*., 2018) owing to its various biological and therapeutic qualities, which include anticonvulsant, anxiolytic, antioxidant, anti-inflammatory, and antibacterial effects (Cardia *et al*., 2018). Some studies have already pointed out some aspects regarding the possible use of lavender (LA) in phytoremediation but not in urban post-industrial sites. Here, we evaluated the ability of *Lavandula angustifolia* Mill. to accumulate and translocate HM from post-industrial brownfields. The specific objectives were to investigate the following: (1) the concentration of HMs (Cd, Cu, Pb, and Zn) in soil; (2) the concentrations of HMs (Cu, Cd, Pb, and Zn) in the root, stem, and leaves of lavender; (3) lavender's potential for phytoremediation as determined by the translocation and bioconcentration factors (BCF).

MATERIALS AND METHODS

The investigation was carried out in Baia Mare, Romania (47°39′N 23°34′E; *Figure 1a*), on a location that had previously been contaminated with HM. The riparian brownfield covers an area of 1.5 ha and is located on the banks of the Firiza River (N 47°40'02.6", E 23°36'21.4"; *Figure 1b*). This site includes an anthropic protosoil (anthropic/urban soil) characterised by different levels of soil HM contamination (Cd, Cu, Pb, and Zn), as a result of mining, metallurgical industry, and urbanisation. The main sources of HM pollution in the area were two metallurgical companies: Romplumb (producer of lead) and Cuprom (producer of refined copper).

(a) (b)

Figure 1 – Location of the experimental site: (a) Baia Mare location within Romania; (b) Experimental site location within Baia Mare

This site is currently under phytoremediation, and one of the plant species introduced to extract the HM from the soil is *Lavandula angustifolia* Mill. LA seedlings were planted in May 2020 in pits with a depth of 20 cm and a distance of 80-90 cm between plants (*Figure 2*).

To fulfil the objectives of the present research, soil and plant samples were collected from the experimental site for chemical analyses (July-August 2021). Each soil/plant sample represented a composite sample of 3 soil subsamples/3 individual plants. The analysed samples were taken from the first 10 cm of soil. Soil and plant samples were previously prepared according to the general protocol, which implies cleaning (in order to remove any debris from soil samples), drying and grinding. Both soil and LA samples were analysed for HM by X-Ray fluorescence (XRF) converted data in 5 replicates. The data recorded by XRF (5 samples/ 5 replicates) were converted to accurate quantitative data through linear regression (data not published; $R^2 > 0.97$ for Cd and Zn and $R^2 > 0.95$ for Cu and Pb), according to the methodology described by Cerdà-Domènech *et al.* (2020).

Soil major indices were also analysed: pH (according to the Romanian standard SR ISO 10390:2015 for soil quality), humus content (by method of wet oxidation), total nitrogen (by the Kjeldahl method) and mobile phosphorous (by the Egner-Riehm-Domingo method).

The translocation factor (TF) was assessed after Takarina *et al.* (2017) according to the following *Equation (1)*:

$$TF = \frac{Ca}{Cr} \quad (1)$$

where: Ca - metal concentration in above/aerial plant parts, Cr- metal concentration in the root.

The bioconcentration factor (BCF) indicator was calculated after Usman *et al.* (2012) according to the following *Equation (2)*:

$$BCF = \frac{Cr}{Cs} \quad (2)$$

The statistical analysis of the results achieved was performed by Statistica vs 10 (t/F-test for single means and partial correlations) and post-hoc Tukey HSD. Effects were accepted as statistically significant if $p \leq 0.05$.


(a)


(b)

Figure 2 – Overview of the experimental procedure:
(a) seedlings planting; (b) lavender installed in the experimental site

RESULTS

Soil chemical composition (from 0-20 cm layer) showed that the soil from the experimental site is moderately acidic (pH in H_2O of 5.52 ± 0.01) with very low humus content (1.52%) and a poor supply of N and P (0.052% N and 4 ppm mobile P). Concerning soil HM content, the analysis performed showed high concentrations for all of the studied trace elements (*Figure 3*). Cadmium and lead found in the soil samples were thirteen times higher than the threshold limit values applied in Romania for HM in soils (the Romanian Order number 756 from November 3, 1997), while the values determined for copper were six times higher, and three times higher for zinc.

High values for Cd, Cu, Pb and Zn were also obtained when LA tissues were analysed, with a different partitioning of HM among plant tissues. Generally, the highest content of the HMs Pb and Cu was reached by aboveground mass compared to that found in the root (*Figure 4*). The results obtained for Zn and Cd followed the same pattern: stem < leaves < root ($p < 0.001$), while for Pb the values were similar to those obtained for Cu ($p < 0.01$), showing that root < stem < leaves.

The results obtained for TF showed significant differences among the four heavy metals studied (*Table 1*). As such, the lowest values of the TF were recorded for Cd, followed by Zn ($p \geq 0.05$). Significantly higher TF values were reached for Cu (1.79, $p < 0.001$) and Pb (3.59, $p < 0.001$). Variations were observed also considering the BCF, with values between 0.44 (for Cu, $p < 0.001$) and 6.66 (for Cd, $p < 0.001$).

DISCUSSION

Phytoremediation is a sustainable and low-cost technique implementing green plants to remove HM from polluted soils (Ashraf *et al*., 2019). As such, the valid candidates for phytoremediation are plant species that are able to install, accumulate, and tolerate HMs in their vegetative organs. This study demonstrated that LA is not only able to grow and adapt well in brownfields but also to accumulate important amounts of HMs among plant tissues.

Soil chemical composition (from 0-20 cm layer) showed that the soil from the experimental site is moderately acidic (pH in H_2O of 5.52 ± 0.01), with very low humus content (1.52%) and poor in supplies of N and P (0.052% N and 4 ppm mobile P).

Generally, a soil pH below 5.5 has negative effects on plant growth, nutrient availability, water solubility, and leaching of metals (Liu *et al*., 2013). Still, Mitreva and Pankov (2018) showed in a previous study that lavender is not demanding with respect to soils, but if a high production of lavender is wanted, then this species should be grown in soils with pH in the range of 5.8 to 8.3.

Concerning the HM concentrations in soil, our results showed that all of the four HMs investigated exceeded the threshold value for uncontaminated soil: Cd and Pb values were thirteen times higher (the threshold for Cd is 1 mg kg^{-1} and for Pb is 20 mg kg^{-1}), Cu values were six times higher (the threshold is 20 mg kg^{-1}), and Zn values were three times higher (the threshold is 100 mg kg^{-1}). The high values achieved for Cd and Pb are also explained by the location of the experimental site in the vicinity of former companies: Romplumb and Cuprom in Baia Mare, producing lead and, respectively, refined copper.

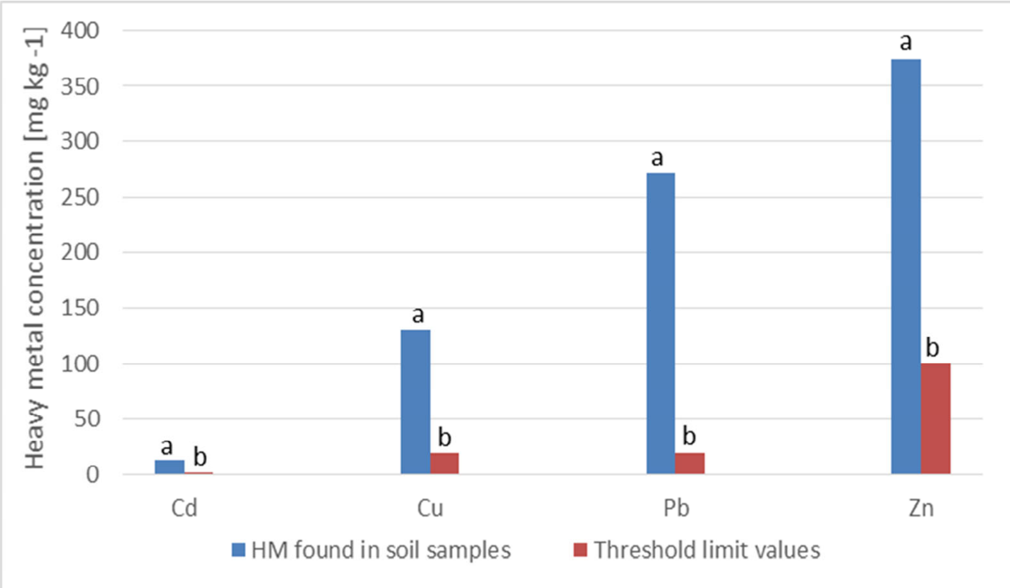

Figure 3 – Correlation between heavy metal concentrations found in soil samples and the threshold limit values according to the Romanian Order number 756 from November 3, 1997

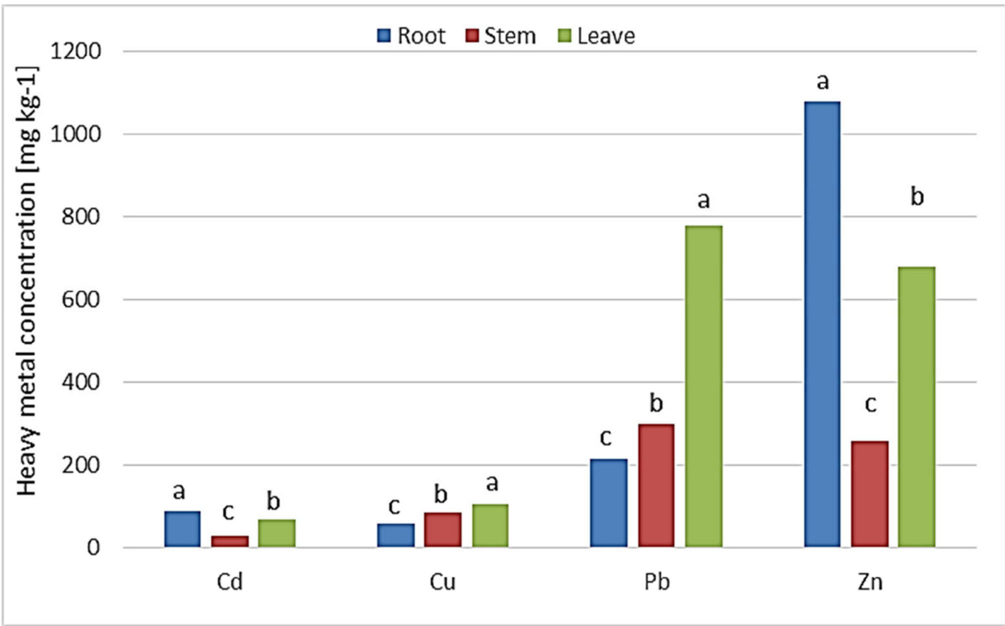

Figure 4 – Heavy metal concentrations found in plant tissue samples

Table 1 – The potential of LA in accumulating HM according to the TF and BCF indices

Indicator	Heavy metal			
	Cd	Cu	Pb	Zn
TF	0.78 ± 0.04^{c}	1.79 ± 0.17^{b}	3.59 ± 0.35^{a}	0.62 ± 0.12^{c}
BCF	6.66 ± 0.42^{a}	0.44 ± 0.02^{d}	1.09 ± 0.05^{c}	2.87 ± 0.23^{b}

Notes: TF - translocation factor and BCF - bioconcentration factor

The matrix of partial correlations between soil properties and heavy metal concentrations in soils (*Table 2*) shows a significant correlation between Pb and Cu ($p \leq 0.05$). A similar response was also reported by Petelka *et al.* (2019) for soil samples collected from a former gold mine located in Ghana. Also, a significant correlation was observed between soil humus and P content, and Zn concentration but not in soil pH and HM concentration in soil, although previous studies demonstrated a negative correlation between soil pH and HM mobility and availability to plants (Bang and Hesterberg, 2004; Zeng *et al.*, 2010). Still, other research also pointed out the lack of a clear trend in the correlation between soil pH and soil HM concentrations (Petelka *et al.*, 2019).

The analysis performed on plant samples showed that the highest content of the HMs Pb and Cu was reached in the stem and leaves and lower values in the root (*Figure 4*). An explanation for the greater concentration of Pb in the leaves and stems could be (according to Angelova *et al.*, 2015) attributed to the woody stem of lavender, which could favour the attachment of the aerosols and their accumulation in the above-ground tissues. The content of Cd and Zn in lavender tissues was high (between 27.1 and 87.3 mg kg^{-1} for Cd and between 260.0 and 1078.1 mg kg^{-1} for Zn), exceeding the critical values for plants, being almost three times higher for Zn and toxic for Cd (where the limit for toxicity is 5 mg kg^{-1}).

One of the most important criteria for the selection of a proper plant species candidate for phytoremediation of HM-polluted soils is the calculation of the bioconcentration and the translocation factors.

Table 2 – Correlations between soil properties and heavy metals content

	pH	Humus	N	P	Cd	Cu	Pb	Zn
pH	1.000							
Humus	0.381	1.000						
N	0.512	0.131	1.000					
P	0.385	0.004	0.126	1.000				
Cd	0.366	0.747	0.878	0.752	1.000			
Cu	0.106	0.487	0.618	0.492	0.260	1.000		
Pb	0.124	0.505	0.636	0.510	0.242	0.018	1.000	
Zn	0.358	0.022	0.153	0.027	0.725	0.464	0.483	1.000

Note: Values marked with red colour are significant, while those marked with blue colour are not significant according to the matrix of partial correlations

In the interpretation of the results, a value higher than 1 for TF reveals the ability of a plant to be used as a candidate for phytoextraction, while a value higher than 1 for BCF shows that the plant is able to bioaccumulate high amounts of HMs (Takarina *et al*., 2017). The results obtained in this study for TF showed that LA can be classified as an accumulator for Cu and Pb since the values reached are higher than 1, revealing that this plant is a suitable candidate for the phytoextraction of these two trace elements (*Table 1*). According to the BCF values, it seems that lavender is able to bioaccumulate high amounts of Cd, Zn, and Pb. Similar findings were reported also by Angelova *et al*. (2015).

CONCLUSIONS

The soil from Baia Mare showed high concentrations of Cu, Cd, Pb, and Zn, such that all of the four HMs studied exceeded the threshold value for uncontaminated soil applied in Romania (especially Cd and Pb). The data obtained from the study allow the assessment that *Lavandula angustifolia* Mill. (LA) can translocate and concentrate copper and lead from the soil in the aerial parts of plants. Being a good accumulator of cadmium, lead and zinc, the plant stands out for its phytoextraction capacity. Even though more research is required for definitive results, since the criteria considered for the selection of proper candidates for phytoremediation include other aspects concerning plant species' capability to adapt well in a brownfield environment, deliver high amounts of biomass, and the ability to accumulate high amounts of heavy metals, our findings confirm that LA is able to grow, tolerate, accumulate, and translocate HM from soil to the above ground plant parts.

Author Contributions: conceptualisation (R.V. and A.M.), methodology (R.V., T.M., A.M. and A.P.), analysis (T.M., A.M., B.P. and A.P.), investigation (A.P., B.P. and T.M.), resources (R.V. and T.M.), data curation (A.M., B.P. and A.P.), writing (A.M., A.P. and B.P.), review (R.V. and T.M.), and supervision (R.V. and T.M.). All authors declare that they have read and approved the publication of the manuscript in this present form.

Funding: This research was funded by the research project UIA04-138 SPIRE - Smart Post-Industrial Regenerative Ecosystem.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Angelova, V.R.; Grekov, D.F.; Kisyov, V.K.; Krasimir, I.I. Potential of lavender (*Lavandula vera* L.) for phytoremediation of soils contaminated with heavy metals. *International Journal of Biological, Food.* **2015**, 9, 465-472.

Ashraf, S.; Qasim, A.; Zahir, A.; Zahir, S.; Ashraf, H.; Naeem, A. Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. *Ecotoxicology and Environmental Safety*. **2019**, 174, 714-727. https://doi.org/10.1016/j.ecoenv.2019.02.068.

Bang, J.; Hesterberg, D. Dissolution of trace element contaminants from two coastal plain soils as affected by pH. *Journal of Environmental Quality*. **2004**, 33, 891-901. https://doi.org/10.2134/jeq2004.0891.

Carabulea, V.; Motelică, D.-M.; Vrînceanu, N.O.; Plopeanu, G.; Costea, M.; Oprea, B.Ș.; Tănase, V. Bioaccumulation of heavy metals in garlic bulbs (*Allium sativum* L.) in correlation with soil from private gardens in the Copșa Mică area, Romania. *Journal of Applied Life Sciences and Environment*. **2022**, 55, 245-255. https://doi.org/10.46909/alse-552061

Cardia, G.F.E.; Silva-Filho, S.E.; Silva, E.L.; Uchida, N.S.; Cavalcante, H.A.O.; Cassarotti, L.L.; Salvadego, V.E.C.; Spironello, R.A.; Bersani-Amado, C.A.; Cuman, R.K.N. Effect of lavender (*Lavandula angustifolia*) essential oil on acute inflammatory response. *Evidence Based Complementary and Alternative Medicine*. **2018**, 1413940. https://doi.org/10.1155/2018/1413940.

Cerdà-Domènech, M.; Frigola, J.; Sanchez-Vidal, A.; Canals, M. Calibrating high resolution XRF core scanner data to obtain absolute metal concentrations in highly polluted marine deposits after two case studies off Portmán Bay and Barcelona, Spain. *Science of The Total Environment*. **2020**, 717, 134778. https://doi.org/10.1016/j.scitotenv.2019.134778.

Greipsson, S. Phytoremediation. *Nature Education Knowledge*. **2022**, 3, 7.

Gupta, A.K.; Verma, S.K.; Khan, K.; Verma, R.K. Phytoremediation using aromatic plants: a sustainable approach for remediation of heavy metals polluted sites. *Environmental Science and Technology*. **2013**, 47, 10115−10116. https://doi.org/10.1021/es403469c.

Laghlimi, M.; Baghdad, B.; El Hadi, H.; Bouabdli, A. Phytoremediation mechanisms of heavy metal contaminated soils: a review. *Open Journal of Ecology*. **2015**, 5, 375-388. http://dx.doi.org/10.4236/oje.2015.58031.

Lamine, S.; Saunders, I. Phytoremediation of heavy-metals-contaminated soils: A short-term trial involving two willow species from Gloucester Willow Bank in the UK. *Minerals*. **2022**, 12, 519. https://doi.org/10.3390/min12050519.

Liu, G.; Xue, W.; Tao, L.; Liu, X.; Hou, J.; Wilton, M.; *et al.* Vertical distribution and mobility of heavy metals in agricultural soils along Jishui River affected by mining in Jiangxi Province, China. *Clean - Soil, Air, Water* **2013**, 42, 10, 1450–1456. https://doi.org/10.1002/clen.201300668

Liu, S.; Yang, B.; Liang, Y.; Xiao, Y.; Fang, J. Prospect of phytoremediation combined with other approaches for remediation of heavy metal-polluted soils. *Environmental Science and Pollution Research International*. **2020**, 27, 16069–16085. https://doi.org/10.1007/s11356-020-08282-6.

Meagher, R.B. Phytoremediation of toxic elemental and organic pollutants. *Current Opinion in Plant Biology*. **2000**, 3, 153−162. https://doi.org/10.1016/S1369-5266(99)00054-0.

Merwin, L.; Umek, L.; Anastasio, A.E. Urban post-industrial landscapes have unrealized ecological potential. *Restoration ecology*. **2022**. https://doi.org/10.1111/rec.13643.

Mitreva, Z.; Pankov, V. Opportunities for growing lavender in areas facing natural constraints exemplified by the Borika village, Bulgaria. *Journal of Soil Science*. **2018**, 3, 134-142.

Petelka, J.; Abraham, J.; Bockreis, A.; Precious Deikumah, J.; Zerbe, S. Soil heavy metal(loid) pollution and phytoremediation potential of native plants on a former gold mine in Ghana. *Water, Air, & Soil Pollution*. **2019**, 230, 267.

https://doi.org/10.1007/s11270-019-4317-4.
Takarina, N.; Tjiong, G.P.D. Bioconcentration factor (BCF) and translocation factor (TF) of heavy metals in mangrove trees of Blanakan Fish Farm. *Makara Journal of Science*. **2017**, 21, 77-8.
Usman, A.R.; Lee, S.S.; Awad, Y.M.; Lim, K.J.; Yang, J.E.; Ok, Y.S. Soil pollution assessment and identification of hyperaccumulating plants in chromated copper arsenate (CCA) contaminated sites, Korea. *Chemosphere*. **2012**, 87, 872–878. https://doi.org/10.1016/j.chemosphere.2012.01.028.
Yang-Guang, G.; Qin, L.; Yan-Peng, G. Metals in exposed-lawn soils from 18 urban parks and its human health implications in southern China's largest city, Guangzhou. *Journal of Cleaner Production*. **2016**, 115, 122–129. https://doi.org/10.1016/j.jclepro.2015.12.031.
Zeng, F.; Ali, S.; Zhang, H.; Ouyang, Y.; Qiu, B.; Wu, F.; Zhang, G. The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. *Environmental Pollution* **2010**, 159, 84-91. https://doi.org/10.1016/j.envpol.2010.09.019.
Zhang, Yi. Cultural sustainability of a post-industrial brownfield in Wanzhou China: maintaining cultural value through brownfield redevelopment. MSc Thesis, Clemson University, 2012.
Zwolak, A.; Sarzyńska, M.; Szpyrka, E. Sources of soil pollution by heavy metals and their accumulation in vegetables: a review. *Water, Air, & Soil Pollution*. **2019**, 230, 164. https://doi.org/10.1007/s11270-019-4221-y.

Academic Editor: Dr. Iuliana Motrescu

Publisher Note: Regarding jurisdictional assertions in published maps and institutional affiliations ALSE maintain neutrality.