BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 67 (71), Numărul 4, 2021
Secţia
CHIMIE şi INGINERIE CHIMICĂ

METHODS FOR THE REMEDIATION OF SOILS POLLUTED WITH HEAVY METALS

BY

IONELA CĂTĂLINA VASILACHI[1] and MARIA GAVRILESCU[1,2,*]

[1]“Gheorghe Asachi” Technical University of Iaşi,
“Cristofor Simionescu” Faculty of Chemical Engineering and Environmental Protection,
Department of Environmental Engineering and Management, Iaşi, Romania
[2]Academy of Romanian Scientists, Bucureşti, Romania

Received: November 7, 2021
Accepted for publication: December 1, 2021

Abstract. Pollution of soils with heavy metals is considered a serious environmental problem at international level. Over time, *in-situ* and *ex-situ* remediation techniques have been developed for areas contaminated with heavy metals, in order to mitigate the risks associated with the environment, animals and human health. Remediation techniques involve mechanisms of degradation, immobilization, isolation or extraction in order to reduce the negative effects of pollutants through chemical, physical or biological remediation processes. Therefore, these techniques have a specific applicability and limitations such as high costs, long time, logistical or mechanical problems. In recent years, phytoremediation has been used as an alternative solution for the heavy metal remediation process due to its advantages as a cost-effective, environmentally friendly and efficient technology, based on the ability of green plants to accumulate heavy metals. This review presents the harmful effects of heavy metal pollution, as well as methods of remedying these environmental contaminants.

Keywords: contaminated sites; ecological risk; phytoremediation; remedial techniques.

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[*]Corresponding author; *e-mail*: mgav@ch.tuiasi.ro

1. Introduction

The presence of contaminants in the environment is closely linked to the deterioration of its quality and, implicitly, of the quality of life, thus justifying the concerns for reducing their impacts. Environmental pollution has become one of the most important and debated issues today. With the industrialization and urbanization, the process of degradation of environmental components has evolved more and more worrying. Environmental pollution with heavy metals is considered a major problem at international level. One of the most important consequences of the current state of growing demand for improved quality of life is the increased exposure to the toxic action of environmental pollutants.

Many countries have signed treaties to monitor and reduce pollution with various contaminants. Moreover, research in this area is receiving increasing attention, as a consequence of the negative effects that environmental pollution has on human health and, in addition to the finding that certain pollutants accumulate in animal and plant cells, which could lead to serious adverse effects. From the known pollutants, heavy metals can generate major threats especially due to their non-biodegradability, persistence, toxicity and accumulation in the food chain (Fig. 1).

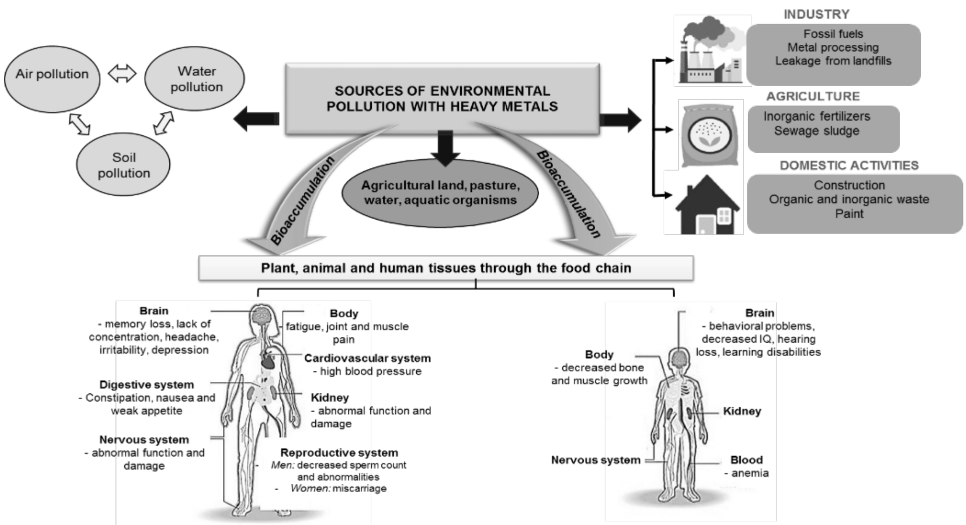

Fig. 1 − Origin and transport of heavy metals in the food chain.

Both the soil and the aquatic environment are complex systems in which physical, chemical and biological processes play a major role in the behavior, transport and reactions in which heavy metals participate. The fate of these contaminants in the environment is influenced by a large number of processes that determine their mobility and behavior. The interaction with soils, surface and deep waters is complex, being controlled by numerous biological, physical and chemical reactions that can occur simultaneously. An understanding of how pollutants are generated and distributed in sediments requires consideration of sources, transport processes, and transformation and degradation mechanisms.

Therefore, there is a vital need to remove or eliminate contaminants from the environment through the use of efficient treatment systems. In this respect, various physical, chemical and biological processes for the decontamination of environmental pollutants can be applied, but special importance is currently given to bioremediation techniques.

2. Heavy Metals in the Environment

Generally the generic name of "heavy metal" is used to designate metals and semi-metals (metalloids) that have been associated with the property of toxicity and ecotoxicity (Duffus, 2002). In summary, the term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. In general, heavy metals are considered those elements whose density exceeds 5 g/cm^3, and the atomic mass is between 63.54 and 200.59 (Ghosh and Singh, 2005).

Rocks and soils are the main natural sources of heavy metals in the environment. Heavy metals are incorporated as microelements in the crystallographic matrix of primary minerals, which were formed during the magma cooling process, by isomorphic substitution, a process in which heavy metals replace other atoms during the crystallization process (Căliman *et al.*, 2009). Therefore, both natural and anthropogenic processes cause the appearance of heavy metals in various environmental components, and with the increase of exploitation and smelting of heavy metals, concern for the quality of the environment has been raised due to large amounts of heavy metals in surface waters, soil and sediments (Masindi and Muedi, 2018). In literature there are presented data according to which the contamination of the soil with heavy metals is determined primarily by municipal and industrial waste, approximately 38%, followed by the commercial/industrial sector by approximately 34% (Panagos *et al.*, 2013).

In soil, heavy metals can be found as free ions or in combinations. Heavy metal ions can be adsorbed by inorganic solids, can form soluble compounds in soil, insoluble inorganic compounds (phosphates and carbonates), complex organic combinations, or metallic silicates, the latter being the most stable form of heavy metals and with the least negative effects on the environment compared to other forms found in the soil (Chibuike and Obiora, 2014; Gavrilescu, 2014). Considering their toxicity, heavy metals can be grouped into (Hlihor, 2014; Tchounwou *et al.*, 2012):

• essential nutrients, such as zinc, iron or cobalt (non-toxic at very low concentrations);

• relatively harmless substances, such as silver or indium;

• very toxic substances in large quantities, for example mercury, chromium, copper, cadmium or lead.

Heavy metals are included in the category of persistent inorganic pollutants (PIPs) used in agriculture, industry and therefore released into the environment, so that at European level there are over 10,000 sites contaminated with heavy metals, meaning that 28.3% of the total area it is affected by pollution with one or more heavy metals, for which the values of concentrations encountered in the soil exceed the maximum allowable limits (Tchounwou *et al.*, 2014; Tóth *et al.*, 2016). The minimum and maximum values of heavy metals concentration detected at European level are presented in Table 1.

At national level, about 6600 hectares are affected by heavy metal pollution, and for about 5700 hectares the values of concentrations of heavy metals found in the soil exceed the maximum allowable limits (Dumitru *et al.*, 2011).

Table 1

Values of Heavy Metal Concentrations Detected in Soil in the European Union (Tóth et al., 2016)

Heavy metal	Detected concentration (mg/kg)		
	Low	Maximum	Medium
Cd	0.02	3.17	0.09
As	0.46	252.53	3.72
Co	0.32	91.89	6.35
Cr	1.57	273.94	21.72
Cu	0.91	159.07	13.01
Hg	0	1.59	0.04
Mn	9.62	2285.23	373.05
Ni	0.36	466.48	16.36
Pb	1.63	151.12	15.3
Sb	0.01	10.91	0.25

Heavy metals tend to be more mobile in acidic soils (Vardhan *et al.*, 2019). A healthy soil is fundamental for the production of food crops, and an accumulation of heavy metals prevent good plant productivity (Jaishankar *et al.*, 2014; Mohammed *et al.*, 2011). An agricultural soil polluted with heavy metals is a serious environmental problem due to the widespread distribution of dangerous heavy metals in the environment and the acute or chronic effects on plant growth. In a study by Khaneghah *et al.* (2020) contamination with potentially toxic elements in cereals and their products has been estimated. The results showed that in processed foods from cereals, the potentially toxic elements, with the exception of Zn and Sn, were smaller compared to unprocessed cereals. For example, in China approximate 10% of agricultural land is contaminated with heavy metals. Countries such as India, Spain, United States, Italy, are threatened by an excess of Cd in soils, and the city of Naples in Italy and Mexico City of soils contaminated with Zn, Pb and Cu (Tang *et al.*, 2019).

At present, given the strong anthropogenic impact in the environment, it is very important to monitor and control the levels of heavy metals in food products, or in ecosystems, because once they enter plant, animal and human tissues through the food chain, inhalation or manual handling, heavy metals can affect the functioning of vital cellular components. In the process of food preparation, metals do not decompose, but on the contrary, their concentration per unit mass increases. It is known that metals have the property of accumulating in the body, so they can slow down or even block intracellular biochemical processes. In addition, most metals have mutagenic and carcinogenic properties (Table 2).

Table 2
Sources and Harmful Effects of Metals on Plants and Human Health

Heavy metal	Sources of pollution	Effects on plants	Effects on humans	References
Zn	Activities such as mining, steel production, burning of coal and waste	It is an essential microelement for plants, but at excessive levels it causes an inhibition of plant growth, leafs wavy and necrosis of the tip the leaf	Over dosage causes fatigue and dizziness	Broadley *et al.* (2007); Rout and Das (2009); Ali *et al.* (2013); ATSDR (2005)
Cu	Mining of copper mines, production of metals, pesticides, fungicides, electrical appliances, burning of fossil fuels, paints	High concentrations of Cu produce oxidative stress on plants, leaf chlorosis and necrosis	Causes kidney disease, of the brain, chronic anemia, cirrhosis, intestinal and stomach irritations	Benavides *et al.* (2005); Ali *et al.* (2013); Yadav (2010); Leal *et al.* (2018)
Cd	Industrial activities such as the production of batteries, pigments, cigarettes	Cd is a non-essential element and has no physiological function. At high levels Cd causes the reduction of photosynthesis, absorption of nutrients and water, the development of soil microflora and is toxic to plants, causes chlorosis,	Cancer, it can cause mutations, it causes chronic anemia, renal insufficiency	Benavides *et al.* (2005); Ali *et al.* (2013); Yadav (2010); Tchounwou *et al.* (2012)

		growth inhibition, redness of the tips		
Pb	Anthropic activities such as the production and exploitation of fossil fuels, combustion, industrial, agricultural, batteries, ammunition	Pb in high concentrations in soil determines the irregular morphology of some plants, induces oxidative stress, affects the growth and photosynthesis process of the plant	Short-term memory loss, reduced intelligence, renal insufficiency, high risk for cardiovascular disease	Shahzad *et al.* (2018); Ali *et al.* (2013); Yadav (2010); Tchounwou *et al.* (2012)
Ni	Chemical industry, metallurgical industry, food processing industry, nickel salts, medicine (dental implants), cigarettes	Ni is an essential component by activating nitrogen who fixing enzymes, but high concentrations of Ni in plant tissues lead to nutrient balance disabilities, causing chlorosis, necrosis and affecting nitrogen metabolism	Lung cancer, throat, sinus, stomach, allergic dermatitis, hepatotoxic, hair loss, neurotoxic	Shahzad *et al.* (2018); Vardhan *et al.* (2019); AbdElgawad *et al.* (2020); Ali *et al.* (2013); Cempel and Nikel (2006)
Cr	Metallurgical industry, chemical industry, industrial activities such as welding of steel, metal processing	Exposure of plants to high concentrations of Cr affects the photosynthesis regarding carbon dioxide fixation, electron transport and enzyme activities, causes growth inhibition on plant, leaf chlorosis, tip branching, nutrient imbalance	Causes hair loss, respiratory irritation, lung or nasal cancer, asthma, dermatitis, kidney, liver and cardiovascular disease	Vardhan *et al.* (2019); Ali *et al.* (2013); Yadav (2010); ATSDR (2008)
Fe	The ferrous metals industry, the production of iron and raw steel	Excess Fe generates free radicals that damage the membrane, of ADN, proteins and weaken cell structure	In excessive amounts Fe can cause liver and brain damage, stomach pain, vomiting or colon cancer	Vardhan *et al.* (2019); Ali *et al.* (2013); Arnarson (2017); Huang *et al.* (2019)
As	Volcanic eruptions, anthropic activities, soil erosion, agricultural products (herbicides, pesticides,	Low concentrations of As stimulate plant growth, but in high concentrations inhibit root growth and plant development, cause	Causes indigestion, carcinogenic risks, vascular and cardiovascular disease,	Tchounwou *et al.* (2012); Finnegan and Chen (2012); Hakeem *et al.* (2014)

	fungicides, algicides), medical field (meds), veterinary medicine (tapeworm treatment)	oxidative stress, wilting, chlorosis, normal functioning of the biochemical function of cells is disrupted, impedes photosynthesis, transpiration	neurological injuryes, diabetes, anemia, affects the respiratory, kidney, gastrointestinal and dermatological systems	
Hg	Electrical industry (batteries, switches), dentistry, industrial processes, production of caustic soda, pharmaceuticals, paints, pesticides	High levels of Hg are toxic to plant cells, cause physiological disorders, cause oxidative stress	Depression, low immunity, anxiety, hair loss, fatigue, insomnia, memory loss, vision disorders, ulcer, kidney injury, brain, lungs	Ali *et al.* (2013); Yadav (2010); Tchounwou *et al.* (2012)

3. Methods Applied for Remediation of Environment Components Polluted with Heavy Metals

Currently, the big problem of soil pollution is the presence of heavy metals on the contaminated sites together with different industrial pollutants, called co-contamination. Heavy metal remediation can be more difficult compared to remediation of organic contaminants, because heavy metals cannot be mineralized in carbon dioxide and water, but can only be transformed into a less toxic form or immobilized to reduce their bioavailability in the environment. Heavy metals also prevent the biodegradation of inorganic and organic contaminants from contaminated sites, which makes soil remediation more difficult (Sharma *et al.*, 2018).

In general, it is difficult to remove heavy metals from the soil, because they do not degrade as organic molecules. However, metals such as selenium and mercury are described as being transformed and volatized by microorganisms (Abdullahi, 2015). The best method for soil remediation is chosen according to the nature, origin and toxicity of the contaminant, the potential related to the degree of contamination, the chemical and physical characteristics of the soil, the time allocated to the remediation, the use of the soil and the cost-benefit analysis of the technology (Lombi and Hamon, 2005). Among the methods used for remediation of polluted soils we mention the physical, chemical, biological, physico-chemical and physico-biological methods (Fig. 2). Conventional methods used to remove heavy metals from the environment are generally expensive and can bring a potential risk due to the possibility of generating hazardous by-products. The primary objective during the remediation is to obtain a set of conditions that are considered environmentally acceptable and that ensure that no future site action is required.

Remediation technologies are classified into four categories based on the processes that the contaminant undergoes: (i) *disposal*: process by which the contaminant or the contaminated environment is physically removed from the site without separation from the host environment; (ii) *separation*: process that involves removing the contaminant from the host environment; (iii) *degradation*: process by which chemical or biological degradation occurs or the neutralization of compounds in which the heavy metal is included in order to obtain less toxic compounds; (iv) *sequestration* (retention): a process that prevents or immobilizes the migration of the contaminant to or near the surface. Disposal and separation are processes that lead to the reduction or removal of the pollutant. Sequestration technologies, on the other hand, control the migration of contaminant to sensitive receptors without reducing or eliminating it.

According to Khalid *et al.* (2017), methods of remediation of soil contaminated with heavy metals can be classified into 5 categories: physical, chemical, electrical, thermal and biological methods, based on insulation (encapsulation), transformation (stabilization, immobilization) and transport (extraction, removal).

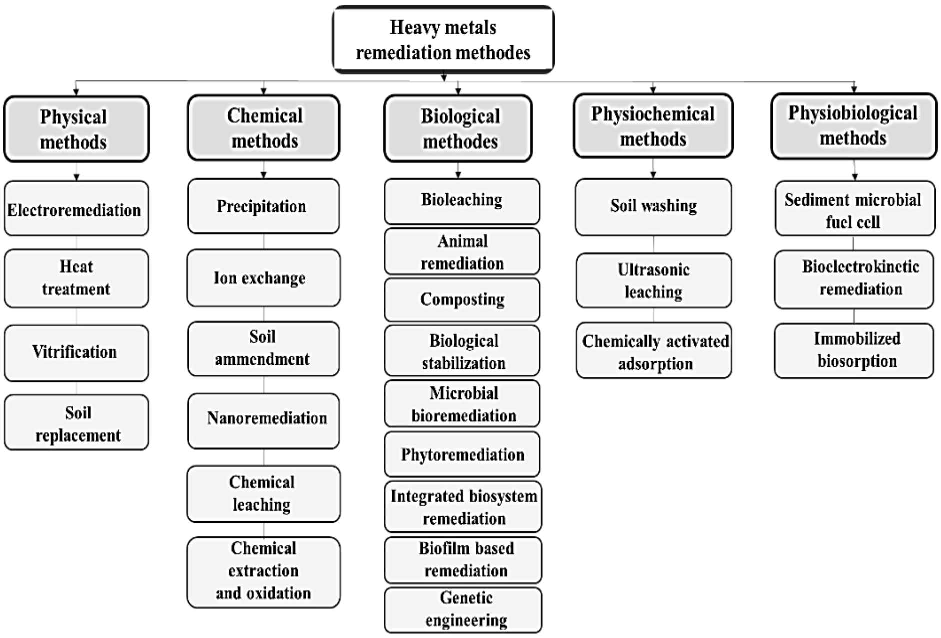

Fig. 2 − Different remediation methods for soil contaminated with heavy metals (Adapted upon Sharma *et al.*, 2018).

Today, biological processes have often proved to be more advantageous because they are environmentally friendly methods and can be implemented directly in contaminated sites. Phytoremediation is one of the most widely used methods of bioremediation, which exploits the ability of plants to absorb and sometimes biodegrade certain contaminants. The phytoremediation process is effective both in depolluting the environment and in preventing and controlling pollution (Kumari *et al.*, 2016).

The remediation methods have both advantages and disadvantages, as well as specific applicability (Table 3). In general, *in-situ* remediation of contaminated soils is more cost-efficient than ex-situ remediation. Also, elimination pollutants is more favourable than retention or immobilization. Remediation techniques such as chemical stabilization, electrokinetic extraction and phytoremediation are the most used for remediation of contaminated soil, and techniques such as solidification and vitrification are the last option in remediation of contaminated soil (Liu *et al.*, 2018).

An alternative to remediation of contaminated soils with heavy metals is the combined remediation. This involves two or more physical, chemical and/or biological remediation techniques. Combined remediation methods such as washing soil coupled with chemical stabilization, chemically assisted phytoextraction, chemical stabilization with phytoremediation or electrokinetic remediation with complexing agents or combined with phytoextraction have attracted the attention of researchers (Gong *et al.*, 2018).

Table 3
Characteristics of Remediation Methods Used for Soils Polluted with Heavy Metals (Gong et al., 2018; Chen and Wang, 2017; Jara, 2007)

Remedial method	Remediation technique	Description	Advantages	Disadvantages
Physical methods	Soil replacement	Replace contaminated soil with uncontaminated soil	It can be used for a small volume of soil, with a high degree of contamination	High cost, contaminated soil needs additional disposal. It cannot be applied to agricultural soils due to possible loss of soil fertility
	Vitrification	High temperatures are used to melt the	It has permanent action, high	High energy losses

		soil and stabilize the heavy metals after cooling	efficiency and long term, substantial reduction of metals and offers the option of reuse	
	Electrokinetic remediation	The technique applies electric current on two parts of the electrolytic tank with saturated contaminated soil	Low energy consumption, applicability on saturated soils with low groundwater flow, with little repair time	Possible at limited depths of treatment, the efficiency of the method is influenced by any heterogeneity of the soil body
	Thermal treatment	The contaminated soil is heated by steam or infrared radiation in order to volatilize the pollutant without burning the contaminants or the environment	It is a simple process, the extraction is efficient, with mercury recovery	High costs, good efficiency only for soils contaminated with a high mercury level, the control of gas emissions is necessary, and the soil structure suffers slight damage
Chemical methods	Chemical stabilization	In the contaminated soils immobilizers are added to reduce the mobility, bioavailability and bioaccessibility of heavy metals in soils	Low cost process, simple and fast	Heavy metals from contaminated soil cannot be removed and neither can the physico-chemical properties be altered
	Stabilization/ solidification	In contaminated soils, reagents are added to transform toxic waste into a more chemically	Low cost, high biodegradation resistance application technique	The high volume of the treated material requires long-term monitoring

		and physically stable form		
	Washing soil	It is made by leaving heavy metals in the soil contaminated with various reagents and extractive substances	It is a fast method, used especially for highly contaminated soils, because it permanently removes heavy metals	High costs, soil structure is damaged, during the remediation process can be removed nutrients from the soil
	Ion exchange	It uses different ion exchange resins as an absorbent, for the absorption of pollutants	Low costs and simple equipment, specific ability to change cationic resins, high treatment capacity, high removal efficiency, fast kinetics, relatively easy operation	Ion exchange is non-selective, high production time, large changes in the pH of the solution, regeneration causes secondary pollution
	Electrochemical removal	Reduction of pollutants using clean reagents: electrons	High separation selectivity, fast and well controlled process, ensures good reduction yields, produces less sludge	High corrosive energy consumption, high operational cost
Biological methods	Microbial remediation	It uses microorganisms, such as bacteria, algae, fungi, to induce adsorption, precipitation, oxidation and reduction of heavy metals in contaminated soil	They do not create any secondary pollution and are practically and economically reliable. Removed contaminants do not require additional	Both plants and soil require long-term monitoring, limited depth capacity

	Phytoremediation	Use of green plants to remove contaminants from the area or to recover them	treatments, and the natural fauna and flora of the soil can be restored to its original shape.	
	Microbial assisted phytoremediation	Plant growth for the phytoremediation process is promoted by bacteria		

4. Phytoremediation-Perspectives and Opportunities for Soil Bioremediation

The researchers showed a major interest in improving an environmentally and financially efficient pollution remediation technique. As mentioned above, chemical and physical remediation methods suffer limitations due to high costs, high labour force and irreversible changes to soil properties, disturbance of soil microfauna or microflora (Ali *et al.*, 2013). So, a major importance is now given to bioremediation techniques (Yadav *et al.*, 2018). They proved to be more advantageous than conventional remediation instruments.

Biological techniques are based on the potential of plants and microorganisms to remove contaminants from the environment by extracting, transferring or accumulating them in biomass (Kumari *et al.*, 2016). In the bioremediation process, the efficiency of plants is limited by the toxicity of the target pollutants and by the capacity of the living organisms involved in the bioremediation to cope with the toxic contaminants in the contaminated environment. One of the most used bioremediation methods for environmental depollution is phytoremediation. The concept of phytoremediation was first introduced in 1983. This can also be called botanical remediation, agro-remediation or green remediation. Phytoremediation is a green solution that uses live plants to reduce, degrade, immobilize or eliminate pollutants from the environment, applicable in situ and based on solar energy. Green plants have a great capacity to absorb pollutants from the environment. This is achieved by their bioaccumulation in roots, stems or leaves and the elimination of pollutants by different techniques (Table 4). Phytoremediation can be applied in combination with other remediation techniques for higher efficiency (Ma *et al.*, 2011; Manara, 2012; Pavel *et al.*, 2013, Ali *et al.*, 2013).

Some heavy metals are poisonous to plants, even in low concentrations of metal ions, while other plants can accumulate heavy metals in their tissues to abnormal states, with no obvious side effects or decreased yields. Of the heavy metals, copper, boron, molybdenum, zinc, iron and nickel are essential for plant growth, but at concentrations above the permissible concentrations are harmful to plants, and metals such as mercury, cadmium, lead and arsenic are not considered essential for plant growth (Vardhan *et al.*, 2019).

AbdElgawad *et al.* (2020) studied the effects of sub-lethal concentrations of Ni, Cu, Zn, Cd on photosynthesis, redox metabolism and metal accumulation in the roots and leaves of maize seed. The hypothesis of the study that redox and non-redox reactive heavy metals could impose quantitative and qualitative differences in redox metabolism could not be validated. However, following this study it was resulted that in the older leaves of corn were found to have higher concentrations of Cu and Cd than the Zn-Ni group. Also the young leaves were less affected by the oxidative stress induced by the heavy metals having as an explanation their growth rate and the larger division, while the older leaves and roots were much more affected.

Phytoremediation is influenced by a variety of factors such as the physical-chemical properties of the pollutants, the characteristics of the plant used, the pH, the content of organic matter, nutrients and soil clay, soil temperature and humidity (Yadav *et al.*, 2018).

Table 4

Description of Phytoremediation Techniques (Ali et al., 2013; Gavrila, 2011)

Techniques	Description
Phytoextraction	It represents the absorption of pollutants from water or soil by the roots of the plants and the accumulation of pollutants in biomass from the soil surface (shoots). For phytoextraction plants with natural ability to accumulate pollutants (hyperaccumulators) can be used or plants that produce large quantities of biomass (cereals) chemically help with additions of substances for an improved capacity to absorb pollutants.
Phytostabilization	It represents the use of certain plant species to stabilize pollutants in the contaminated environment. This technique is used to reduce the bioavailability and migration of pollutants into groundwater or their entry into the food chain.
Phytofiltration	Removal of pollutants from wastewater or surface waters contaminates plants. Phytofiltration can be rhizofiltration (are used plant roots), caulofiltration (using shoots) or blastofiltration (using seedlings).
Phytodegradation	It represents the degradation of pollutants from the environment by plants through enzymes such as oxygenases or dehalogenases. Phytodegradation is limited, because heavy metals are non-biodegradable.
Phytovolatilization	It represents the absorption by the plants of pollutants from water or soil, transforming them into a volatile form and subsequently released into the atmosphere through the leaves. A disadvantage of this technique is the incomplete elimination of

	the pollutant and its transfer to another environment component, the atmosphere.
Rhizodegradation	It represents the decomposition of organic pollutants from the soil with the help of microorganisms from the rhizosphere. The rhizosphere is extended about 1 mm around the root of the plant, being under the influence of the plant. The increased degradation of pollutants in the rhizosphere is due to the high number of microbial metabolic activities. This can stimulate microbial activity in the rhizosphere about 10-100 times more by creating a nutrient-rich environment from plant roots.
Phytodesalination	It is a developing phytoremediation technique that uses halophyte plants to eliminate excess salts from saline soils.

Biomass resulting from the phytoremediation process must be disposed of or stored correctly so that it does not have environmental risks (Yadav *et al.*, 2018). Following studies by Song and Park (2017) it was shown that the volume of biomass can be reduced by composting, although treatment would be necessary before eliminating the biomass of contaminated plants. Also, the biomass that results from the phytoremediation process can be burned. This offers the advantage of the sale of energy from combustion, and the remaining ash is considered "bio-ore". This bio-ore could be processed for the recovery of heavy metals (phytomining) (Ali *et al.*, 2013).

Many researches have shown that phytoremediation with cereals such as corn (*Zea mays* L.) or wheat (*Triticum aestivum* L.) can remedy soil contaminated with pollutants, and the resulting biomass is used for bioenergy production. So, fossil energy sources could be replaced (Cheng *et al.*, 2015).

5. Conclusions

Contamination of the environment with heavy metals is a global challenge, and remediation technologies have advanced greatly in recent years. This review highlights the knowledge, effectiveness of remediation techniques and environmental performance instruments that have been applied, studied and demonstrated at the field level.

Physical remediation methods can remove pollutants from the environment, but are costly and have harmful effects on the environment. Chemical methods are fast, easy to apply and relatively inexpensive, but they do not remove all contaminants and require long term monitoring. Biological remediation methods are the most economically, ecologically and sustainably profitable. Primarily, phytoremediation offers significant results in the depollution of soils contaminated with heavy metals.

Acknowledgements. This work was supported by a grant of a grant of the Romanian Ministry of Education and Research, CCCDI - UEFISCDI, project number PN-III-P2-2.1- PED-2019-5239, Contract no. 269PED/2020, within PNCDI III.

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METODE DE REMEDIERE A SOLURILOR POLUATE CU METALE GRELE

(Rezumat)

Contaminarea solurilor cu metale grele este considerată o problemă gravă de mediu la nivel internațional. De-a lungul timpului au fost dezvoltate tehnici de remediere *in-situ* și *ex-situ* pentru zonele contaminate cu metale grele, în vederea atenuării riscurilor asociate mediului, animalelor și sănătății umane. Tehnicile de remediere folosesc mecanisme de degradare, imobilizare, izolare sau extracție pentru a reduce efectele negative ale poluanților prin procese de remediere chimică, fizică sau biologică. Prin urmare, aceste tehnici au o aplicabilitate și limitări specifice precum costuri mari, timp îndelungat, probleme logistice sau mecanice. În ultimii ani, fitoremedierea a fost folosită ca soluție alternativă pentru procesul de remediere a metalelor grele datorită avantajelor sale ca tehnologie rentabilă, prietenoasă cu mediul și eficientă, bazată pe capacitatea plantelor verzi de a acumula metale grele. În această lucrare sunt prezentate efectele nocive ale poluării cu metale grele, precum și metodele de remediere a acestor contaminanți din mediu.