Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

REVIEW OF METHODS FOR REMEDIATION OF POLLUTED SOILS IN URBAN AREAS

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Abstract

Urban soils are strongly affected by both natural factors: wind, water, freeze-thaw processes, heat, but also by human activity. Soil pollution caused by human activities is often associated with modernization, industrialization, metal extraction activities, oil extraction, inadequate waste storage and pesticide application. Soil pollution is one of the major effects of human technological progress. The impact of soil pollution is not limited to the soil and its organisms, but affects every sector, to humans: human health, plant growth, air pollution, reduced soil fertility, changes in soil structure, impact on ecosystem and biodiversity, contamination of water sources. For this reason, the phenomenon of soil pollution needs to be remedied. This article aims to evaluate the specialized articles and highlight the methods used to remedy polluted soils in urban areas. Remedial methods can be phytoremediation or zooremediation. The remedy can be done ex-situ and in-situ. Soils in urban areas have not received adequate attention and data on this subject are scarce so far, although constraints on soil quality in congested urban areas are acute.

Key words: *methods, pollution, remediation, urban soils.*

INTRODUCTION

Soil is one of the most important resources of the biosphere (Izquierdo et al., 2005). It must be protected because it performs many ecosystem services: it determines the production and productivity of plants, supports the degradation of organic matter and the nutrient circuit (Santorufo, 2012), is a natural buffer for chemicals in the atmosphere (Onete et al., 2009; Ștefănuț et al., 2018), hydrosphere and biota (Onete, 2008; Onete & Paucă-Comănescu, 2008). Soil can be affected by natural factors: wind, water, freeze-thaw processes, heat), but also to a large extent by human activity (Craul, 1985; Hartley et al., 2008). Urban areas are the socio-ecological systems that represent a mix of land uses and comprise the highest percentage of the human population (Li et al., 2018). Recently, the human population has grown exponentially, and for this reason there are needed new living spaces, jobs especially in urban areas (Onete et al., 2010; Agrawal et al., 2020; Manu et al., 2021; O'Riordan et al., 2021). As urbanization is increasing in most of the world, this has implications for the infrastructure needed to support urban growth (McIntyre, 2020; Zissimos et al., 2021). Soils in urban areas called "brown infrastructure" provide multiple ecosystem services (nutrient cycling, carbon sequestration, etc.) (Calzolari et al., 2020), functioning as a source of nutrients for plant growth, called "green infrastructure" important in urban water quantity and quality management ("blue infrastructure") (Trammell et al., 2020). All these components of urban systems are interconnected and influence each other.

As cities become more crowded, pollution in urban areas is an increasing problem (Vara et al., 2012; Ianoș & Jones, 2019; Joyner et al., 2019). The soils undergo physico-chemical changes, through dry and wet depositions (Fowler, 2002) or direct impact (transport, construction, inadequate waste storage (Santorufo, 2012; Kumar et al., 2021), extraction of metals, petroleum substances, application pesticides (Zalesny et al., 2021), excessive use of fertilizers (Muthukumar et al., 2021). Due to the increase of pollutants type (diversity) and intensity, there are also related problems, such as: climate change, loss of biodiversity (Onete, 2010), acid rain, earthquakes, landslides, floods (Verma, 2021), changes in land use (Petrişor et al., 2020), habitat fragmentation or even loss, changes in plants and invertebrate communities, etc. (Santorufo, 2012; Bielińska, 2013; Manu et al., 2018). The impact of soil pollution results in small concentration of nutrients (Mónok et al., 2021), high degree of compaction, too little differentiated stratification, altered structure of soil invertebrate communities (Jim, 1998; Li & Huang, 2007) from bellow and above ground.

Because of the complex effects of soil pollution, researchers draw attention to the importance of studying soil fauna as indicators of soil quality (Manu et al., 2018). Many studies have been conducted on one of the biggest issues related to urban soil pollution: heavy metal pollution (Pb, Zn, Cu, Cr, Ni) (Damodaran et al., 2011; Manu et al., 2018; Ștefănuț et al., 2017; Damasi et al., 2018). Heavy metals are non-degradable compounds so they remain stored in plant tissue subsequently consumed by animals and humans (Hrynkiewicz & Baum, 2014; Verma, 2021). They are naturally found in the soil due to geological processes (Li & Huang, 2007), but they are largely the result of activities in agriculture and industry (Vara et al., 2012; Cai et al., 2013; Li et al., 2013; Lee et al., 2021). Heavy metal contamination has no color or odor, so it is very difficult to identify them (Su, 2014). Lead, for example, affects many physiological systems, with its action beginning in the womb. Children are most vulnerable because their bodies absorb lead at a much higher rate than an adult's body (Obeng-Gyasi et al., 2021).

Polycyclic aromatic hydrocarbons (PAHs) have also strong impact on the soil (Indelicato, 2014; D'Souza et al., 2015; Alegbeleye et al., 2017). Moreover, it has been shown to have carcinogenic, teratogenic and mutagenic effects on humans (Alegbeleye et al., 2017; Adimalla et al., 2020).

As the soil is affected, the effects cascade along the food web, largely affecting the growth of plants, animals and, finally, human health (Onete et al., 2009; Ștefănuț et al., 2017; Brevik et al., 2020; Verma, 2021). Urban biodiversity is a crucial component of the urban system and have great ecological and cultural importance (Onete, 2008; Onete & Ion, 2008; Onete & Manu, 2013). Currently, nature conservation is not one of the priorities of the urban environment. Many areas that should be preserved are sold to the private sector for the development of residential complexes, hotels and shopping centres (Onete & Paucă-Comănescu, 2011).

The solution for all these problems is called remediation. This term refers to the way in which a problem can be solved, and when it is related to the environment, it is called bioremediation (Lynch & Moffat, 2005; Khan & Desai, 2010; Hussain et al., 2021; Verma, 2021). Researchers are concerned with identifying several bioremediation methods, because there is obviously no generally valid method applicable to any polluted environment (Verma, 2021). Bioremediation is influenced by environmental conditions and has the role of reducing or eliminating contamination (Lynch & Moffat, 2005; George et al., 2017; Verma, 2021). It is efficient and does not require high costs (Dotaniya et al., 2018; Urbaniak & Mierzejewska, 2019; Igun et al., 2019). Moreover, it has a low negative impact on the physical and chemical properties of the soil (Foght et al., 2001; Wolejko et al., 2016; Williams & Amaechi, 2017). The purpose of this paper was to identify the remediation methods (techniques) of polluted urban soil existing so far and what is their specificity.

MATERIALS AND METHODS

Out of the total articles (134), have been chosen for the present paper only those that detailed urban soil remediation methods (96). We used search engines Web of Science and Google Scholar following the keywords: urban soils, remediation methods, pollution, remediation. The information was extracted and introduces in a database for further studies.

RESULTS AND DISCUSSIONS

In the literature, two main approaches have been differentiated in terms of remediation: an approach based on external methods of soil restoration (engineering approach) and one involving the manipulation of processes inside the soil for immobilization, transformation and degradation of pollutants (fertilization with organic amendments, revegetation, etc.) (Haimi, 2000). In order to restore an ecosystem, it must be taken into account that it is characterized by multiple trophic interactions, the properties of the soil, fauna and vegetation being interdependent and closely correlated (Civeira & Lavado, 2008; Manu et al., 2019).

Depending on the organisms or complex substances used in the remedy, the methods may be multiple, as it is specified bellow.

Micro-remediation

Micro-remediation is the phenomenon by which microorganisms that have the ability to degrade pollutants return the soil to the natural circuit (Borozan et al., 2021).

Microorganisms are responsible for the degradation processes of pollutants, a method based on an ecological approach.

Microbial populations are key to maintaining soil quality by mediating the processes of organic matter transformation and nutrient cycle (Izquierdo et al., 2005; Abdulsalam et al., 2012). According with different types of pollution, researchers used species or groups of species for micro-remediation (Table 1).

Table 1. Species used for micro-remedial remediation

Species used	Type of pollution/ problem	References
Bacteria	Oil contamination	Abdulsalam et al., 2012
Pseudomonas sp., *Arthrobacter* sp., *Alcaligenes* sp., *Corynebacterium* sp.	Polycyclic Aromatic Hydrocarbons	D'Souza et al., 2015
Pseudomonas sp., *Alcanivorax* sp., *Microbulbifer* sp., *Sphingomonas* sp., *Micrococcus* sp., *Cellulomonas* sp., *Dietzia* sp., *Gordonia* sp., *Marinobacter* sp., *Mycobacterium* sp., *Haemophilus* sp., *Rhodococcus* sp., *Paenibacillus* sp., *Bacillus* sp., *Aeromonas* sp., *Burkholderia* sp., *Xanthomonas* sp. *Micrococcus* sp., *Arthrobacter* sp., *Acinetobacter* sp., *Corynebacterium* sp., *Enterobacter* sp.	Polycyclic Aromatic Hydrocarbons	Alegbeleye et al., 2017
Bacillus subtilis, Candida bombicola, Pseudomonas aeruginosa, Arthrobacter sp.	Oil contamination	Zhang et al., 2020
Pseudomonas sp., *Enterobacter* sp., *Streptomyces* sp., *Rhodococcus* sp., *Amycolatopsis* sp., *Escherichia* sp., *Bacillus* sp., *Micrococcus* sp.	Cu, Zn, Fe	Borozan et al., 2021
Pseudomonas fluorescence, Bacillus sublitis (Bacillus licheniformis, Bacillus circulans, Bacillus megaterium)	Oil-Contaminated Soil	Muthukumar et al., 2021

Phytoremediation

This method defines the bioremediation of contaminated air, soil and water using plants (Table 2) (Lee et al., 2021; Zalesny et al., 2021), based on the role of vegetation to take over and degrade contaminants or reduce their movement (phytostabilization) (Lynch & Moffat, 2005). The used plant species must be tolerant to heavy metals in order to be involved in phytostabilization actions, also known as in situ inactivation or phytoimmobilization (Neagoe et al., 2014). Plants are used to immobilize and physically stabilize contaminants in soil and groundwater by absorbtion at the roots and accumulation by the roots or precipitation in the rhizosphere. Reduces the bioavailability of heavy metals in the soil (Dabrowska et al., 2021). Phytoremediation is a promising method: does not harm the environment, is cost-effective and affordable, easy to implement and maintain, does not depend on artificial energy inputs, socially accepted, minimally invasive and sustainable. This is accomplished through several steps: degradation, transformation, extraction, and immobilization (D'Souza et al., 2015; George et al., 2017; Zalesny et al., 2021). It is a complex techniques that comprise several methods: phytoextraction (use plants to extract and remove heavy metals from the soil), phytovolatilization (plants absorb organic and inorganic pollutants from soil or water and volatilize them into the atmosphere in a modified or unchanged form at relatively low concentrations), phytofiltration (hydroponic plant cultures are used to absorb and adsorb heavy metal ions from groundwater), phytodegradation (organic compounds are degraded by the enzymatic activity of plants), rhizofiltration (plants are used to remove contaminants from the solution around the root zone) (Su et al., 2014; Gupta et al., 2016; Wolejko et al., 2016; Damasi et al., 2018; Padoan et al., 2020; Verma, 2021; Zalesny et al., 2021).

Phytoremediation has generated significant variations in soil chemistry. Compounds released by plants dissolve toxic substances (heavy metals) resulting in increased absorption of chemicals from the soil, thus decreasing their concentration in the soil. Different species are used singular or in combination (Table 2).

Table 2. Species used for phytoremediation remediation

Species used	**Type of pollution/problem**	**References**
Casuarina equisetifolia, Anacardium occidentale	Heavy metals	Izquierdo et al., 2005
Festuca arundinacea, Lolium perenne	Cd, Cr, Cu, Ni, Pb, Zn	Civeira & Lavado, 2008
Agrostemma githago, Trifolium pratense	Derelict and neglected site conditions (e.g. low fertility)	Hartley et al., 2008
Brassica juncea	Cr, Ni, Pb, U, Zn, Cu	Indelicato, 2014
Brassica napus, Eichhoria crassipes, Hydrilla verticillata	Cr, Pb, Hg	Indelicato, 2014
Cocos nucifera , Zea mays, Helianthus annus	Cs, U	Indelicato, 2014
Salix viminalis, Cynodon dactylon	Polycyclic Aromatic Hydrocarbons	Indelicato, 2014
Cistus salvifolius, Aster sp., *Hypericum perforatum, Achillea millefolium, Allium schoenoprasum*	Pb, Cd, Zn	Indelicato, 2014
Cruciferae, Brassica sp., *Alyssums* sp., *Thlaspi* sp.	Heavy metals	Su et al., 2014
Cymbopogon jwarancusa, Helianthus annuus	Polycyclic Aromatic Hydrocarbons	D'Souza et al., 2015
Hibiscus cannabinus	Heavy metals	Taiwo et al., 2015
Brassica juncea, Helianthus annuus	Co, Cr, Cu, Ni, Pb, Zn	Damasi et al., 2018
three Populus clones, three Salix hybrids, and three Robinia genotypes	Zn	Padoan et al., 2020
Agrostis capillaris	Heavy metals	Neagoe et al., 2014

Phytobial remediation

This method of remediation combines remedial techniques using plants and their associated microorganisms. Cultivated plants are colonized by symbiotic microorganisms that degrade pollutants, helping plants to use them in the photosynthetic process (Lynch & Moffat, 2005).

Zooremediation

This remedial technique uses different animal species to remedy a polluted area (Hankard et al., 2005; Kardousha, 2007; Dada et al., 2015). The direct effect of zooremediation is absorption, accumulation and transformation of pollutants. The main indirect effect of zooremediation is the stimulation of the microbial population due to the release of nutrients, enzymes and some metabolites (Gudimov, 2002). Invertebrate species can be used as indicators of the status of polluted areas both before and after bioremediation (Izquierdo et al., 2005; Manu et al., 2021). Animal species used for this purpose include invertebrates (acarina, collembola, maggots, earthworms) (Hankard et al., 2005; Santorufo et al., 2012; Su et al., 2014), fish, oysters, shells, polychaetes, sponges and earthworms (Dada et al., 2015). They can help to remove a wide range of organic and inorganic contaminants, such as pesticides, polycyclic aromatic hydrocarbons, crude oil, and heavy metals from the soil (Dada et al., 2015; Jóźwiak et al., 2019).

Many methods of assessing the toxicity of an area use only the survival of the species of interest as an indicator, but other parameters are also important, such as: growth, reproduction, structure of the invertebrates communities in that area, etc. (Haimi, 2000). There are multiple methods of zooremediation: zooextraction (species that have the ability to extract and accumulate pollutants in their tissues) (George et al., 2017), zoostabilization (invertebrates in the soil and on its surface can stop the migration of pollutants by accumulating them in their own cells), zoodegradation (toxic substances are degraded by the used species) (Kardousha, 2007; Jóźwiak et al., 2019).

Mycoremediation

This method of bioremediation is performed by fungi by manipulating the rhizosphere (Damodaran et al., 2011; D'Souza et al., 2015) for eliminating contaminants, including heavy metals (Dada et al., 2015) (Table 3).

Contaminated soils which are poor in nutrients can be enriched by inoculating the substrate with mycorrhizal fungi (Constantinescu et al., 2019).

Table 3. Species used for mycoremediation remediation

Species used	**Type of pollution/problem**	**References**
Saccharomyces cerevisiae	Cd, Pb	Damodaran et al., 2011
Arbuscular mycorrhizal fungi (AMF)	Heavy metals	Neagoe et al., 2014
Gomus intraradices	Cr	Su et al., 2014
Aspergillus ochraceus, Cunninghamella elegans, Phanerochaete chrysosporium	Polycyclic Aromatic Hydrocarbons	D'Souza et al., 2015
Arbuscular mycorrhizal fungi	Co, Cr, Cu, Ni, Pb, Zn	Damasi et al., 2018
Trichoderma sp., *Aspergillus* sp., *Mucor* sp., *Rhizopus* sp., *Pleuritus* sp., *Penicillium* sp.	Heavy metals	Borozan et al., 2021

Phycoremediation

Defined as the use of algae for waste or wastewater treatment (Phang et al., 2015; George et al., 2017). To remove heavy metals from the environment, Borozan et al. (2021) used several species (*Asparagopsis* sp., *Codium* sp., *Padina* sp., *Cystoseira* sp.).

Use of compost

Compost is a natural agricultural fertilizer, obtained by the slow fermentation of various plant and animal waste, mixed with some mineral substances (food waste, sawdust, banana peels, rice, coconut); these are also called biostimulators (Nwogu et al., 2015; Taiwo et al., 2015; Obrycki et al., 2017; Williams & Amaechi, 2017). For example, the compost can be obtained by mixing cattle manure with sawdust and some plant species in varying proportions. This mixture is allowed to decompose under aerobic conditions, it is periodically watered until its color is a dark brown, which means that it has turned into humus (Taiwo et al., 2015).

It is a source of nutrients that improve soil aeration and make it more fertile, having the role of biostimulation (Muthukumar et al., 2021). Compost can increase the water retention capacity in the soil, promote aeration and increase soil conservation (Gupta et al., 2016; Taiwo et al., 2016; Verma, 2021). Compost is a method of remedying nutrient-poor urban soil. The concentration of nutrients needed by the plants in the soil can be increased by introducing compost into the soil. The purpose of composting is to increase the activity of microorganisms (providing nutrients) that play a role in degrading contaminants, but also for soil fertilization (Obrycki et al., 2017; Constantinescu et al., 2019; Kranz et al., 2020; Muthukumar et al., 2021).

There are studies using vermicompost. This involves the joint action of earthworms and microorganisms. Vermicompost is a peat-like material with excellent structure, porosity, aeration, drainage and moisture retention capacity. It has special properties for usage in agricultural, pharmaceutical, cosmetic, food and energy industries (Chaudhary et al., 2004; Sanchez-Hernandez and Domínguez, 2017; Mills et al., 2020).

Animal waste

A very common method uses of manure for soil remediation. The manure might be provided by sheep, pigs, cattle, goats, birds and is an important source of nutrients that enriches the soil with organic matter (Arifin et al., 2006; Gupta et al., 2016; Masarirambi et al., 2012).

The method comes from agriculture and uses manure from cattle as a biofertilizer (Gupta et al., 2016). It contains cellulose, protein, hemicellulose and minerals such as nitrogen, potassium, magnesium, calcium, sulphur and also microbial communities, fungi, protozoa, yeast. Goat manure is a stimulant of bacterial activity and helps reduce the amount of hydrocarbons in the soil (Nwogu et al., 2015; Williams & Amaechi, 2017; Muthukumar et al., 2021).

The location of remediation techniques

Depending on the location of the polluted site, remediation techniques can be performed both ex-situ and in-situ (Gillespie & Philp, 2013; Zhang et al., 2020; Verma, 2021). Ex-situ remediation techniques can be: suspension phase (the soil is combined with water in a large reactor and homogenized to make contact between microorganisms and contaminants), solid phase (humidity, temperature, nutrients and oxygen are controlled to increase the rate of degradation), biocells (accumulation of contaminated soil in piles and stimulation of microbial activity by aeration or by the addition of nutrients, minerals or moisture) (Khan & Desai, 2010; Abdulsalam et al., 2012; Indelicato, 2014). In situ remediation is performed at the site of contamination by several methods: bio-venting (it uses microorganisms to degrade the organic constituents adsorbed on the soil), bioslurping (use of improved vacuum dehydration technologies to remedy areas contaminated with hydrocarbons), biosparging (technology that uses native microorganisms to biodegrade saturated organic constituents. Oxygen and nutrients are injected into the saturated zone to increase the biological activity of native microorganisms), bioaugmentation (the practice of adding microorganisms from underground cultivation in order to biodegrade certain soil and groundwater contaminants) (Khan & Desai, 2010; Díaz-Sanz, 2015; Wolejko et al., 2016; Urbaniak & Mierzejewska, 2019; Igun et al., 2019; Muthukumar et al., 2021).

Urban management activities

Soil management in urban areas should aim to reduce the concentration of pollutants and ensure that the physical, chemical and biological properties of the soil allow it to function properly (Obrycki et al., 2017). From a managerial point of view, soil remediation can be done in two ways: natural remediation, when it is taken an action, nothing is added in the soil, and through various monitoring activities, researchers/managers make sure that the disappearance of contaminants is due to present soil organisms and not due to contaminant dilution or migration (Dabrowska et al., 2012; Díaz-Sanz, 2015; Wolejko et al., 2016); remediation throw engineering activities - with different degrees of interventions/effective actions (the soil is excavated, treated directly in containers built in a controlled environment and returned to the polluted area) (Litchfield, 2005).

CONCLUSIONS

At present, there is relatively little information on the impact of human activities on organisms in urban soils. Soil studies, too long neglected in urban planning programs, should be seen as an indispensable part of management. The ecology of communities of microorganisms, algae, fungi, invertebrates in urban systems is not sufficiently studied despite their importance for human health. Soil invertebrates are useful indicators of human activity affecting soil in urban areas.

They have a regulating role on the soil trophic network and have effects on soil pedogenesis.

Remediation of urban soils can sometimes be costly, which is why remediation techniques are adopted that are cost-effective. The city and nature are treated as elements in antithesis. Soil management in urban areas is a foreign concept, which is rarely addressed in cities. Many remediation techniques are expensive and if not properly managed can lead to several disadvantages. The issue of urban soil pollution is of particular importance to cities and to people's health.

ACKNOWLEDGEMENTS

Thanks to colleagues Dr. Marilena Onete and Dr. Minodora Manu for guidance in this work. The results were obtained in the framework of Doctoral School of Biology, Faculty of Biology, University of Bucharest. The study was funded by project no. RO1567-IBB01/2022 from the

Institute of Biology Bucharest of Romanian Academy.

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