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ANALYSIS OF THE EXISTING RESEARCH RELATED TO THE USAGE OF ORNAMENTAL PLANTS IN PHYTOREMEDIATION

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Abstract

UNEP defines phytoremediation in its Freshwater Management Series no. 2 newsletter as "the efficient use of plants to remove, detoxify or immobilise environmental contaminants in a growth matrix (soil, water or sediments) through the natural biological, chemical or physical activities and processes of the plants". Although multiple studies have been developed for heavy metals contaminated sites, most of the phytoremediation methods include low cost vegetation with minor landscape value. There are a small number of studies which have taken into consideration the landscaping design in the context of urban areas by using ornamental plants for phytoremediation, thus improving both the quality of the natural resources and the urban or industrial landscape of a given area. Integrating site remediation with landscape design is a necessity for remediation cost reduction, urban planning improvement and it may be considered as a measure for improving the companies' social responsibility commitment. The current study aims at identifying the current state of the research and general practice regarding the usage of ornamental plants for phytoremediation of contaminated sites.

***Key words**: environment, rehabilitation, pollution, phytoremediators, Romania.*

INTRODUCTION

The first references to environmental protection were inserted in the European Union legislation through the Single European Act signed in 1986. Therefore, the Treaties establishing the European Communities was amended by adding Title VII Environment under Part Three of the EEC Treaty, articles 130r, 130s and 130t. The objectives established through article 130r, par. 1 were the following:

- To preserve, protect and improve the quality of the environment;
- To contribute towards protecting human health;
- To ensure a prudent and rational utilization of natural resources.

Based on the definition provided by Oxford Dictionaries, the environment represents the surroundings or conditions in which a person, animal, or plant lives or operates. In conclusion, the environment includes both the biotope, as well as the biocenosis.

It may be concluded, that all the three objectives are referring also to the remediation of contaminated sites, which has been neglected in Romania in the past years.

The last regulation adopted in Romania with regard to the remediation of contaminated sites is the Government Decision (GD) no. 1403/2007 on the rehabilitation of areas where soil, subsoil and terrestrial ecosystems were affected. Although GD no. 1403/2007 is a valid general policy for contaminated sites, the National Strategy and National Plan for the Management of Contaminated Sites in Romania developed in 2015 outlined several weaknesses which include an unclear legislation regarding the methodology for remediation of contaminated sites.

In 2017, the Ministry of the Environment published a public auction for "Services for the development of the methodology and content of the geological report for investigation and assessment of the pollution of soil and subsoil, criteria and indicators for the assessment of the geological media, of the methodology for the rehabilitation of the geological medium of contaminated sites, of clear criteria for intervention through remediation actions (prioritisation criteria for contaminated sites), code SIPOCA 21", but the methodologies were not published yet and no timeline was provided.

Based on the Remediation Technologies Screening Matrix and Reference Guide 4th Edition prepared by the U.S. Department of Defence, phytoremediation is suitable for soil, sediment, bedrock and sludge, as well as groundwater, surface water and leachate. Although the remediation method is considered as above average developed with relatively low costs, longer remediation time is necessary as compared to other remediation methods.

Typical phytoremediation methods include the following: enhanced rhizosphere biodegradation, phyto-accumulation, phyto-degradation and phyto-stabilization, which have been depicted in the figure below.

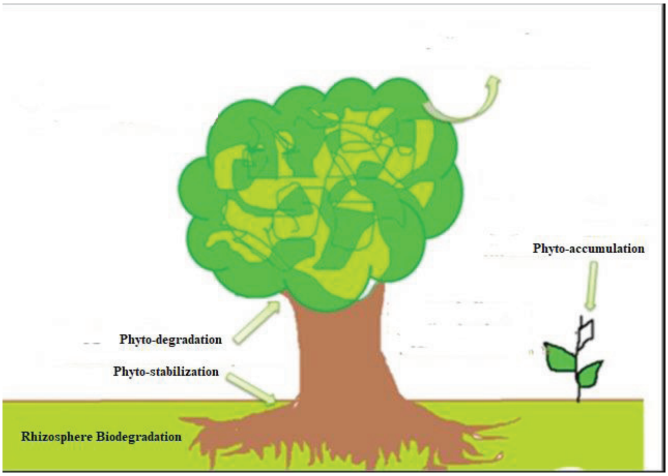

Figure 1 – General Phytoremediation Process (adapted from Verma, 2017)

Enhanced Rhizosphere Biodegradation takes place in surrounding plant roots by releasing natural substances which supply nutrients to microorganisms enhancing their biological activities.

Phyto-accumulation takes place in plant shoots and leaves where contaminants accumulate after plant uptake through roots.

Phyto-degradation takes place in plant tissues which produces enzymes which enable contaminant degradation.

Phyto-stabilization takes place at the interface of roots and soil by immobilizing contaminants. (Van Deuren, 2002)

As all remediation methods should be as costly-effective as possible, it is necessary to identify the most suitable measures which might reduce costs on the long term. As a result, using ornamental plants for remediation might enhance compliance with land planning requirements, improve the urban landscape in contaminated areas and provide an example for green buildings.

MATERIALS AND METHODS

In order to analyse the existing research related to the use of ornamental plants for phytoremediation of heavy metals contaminated sites, several aspects were taken into consideration as follows:

- General phytoremediation potential;
- Types of heavy metals considered by researchers;
- Types of ornamental plants exposed to various concentrations of heavy metals;
- Potential advance of the research related to the phytoremediation process.

The current paper includes both articles published in peer reviewed journals and books written by specialists.

RESULTS AND DISCUSSIONS

Heavy metals are usually generated in various anthropic activities which may generate chemical releases of fertilizers, pesticides biosolids and manures, metal mining, milling processes and industrial wastes, as well as air-borne sources. Contamination of soil and groundwater may occur and heavy metals may be adsorbed through slow or fast reactions. The most common heavy metals which are analysed as contaminants in accordance with the applicable legislation in Romania are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), mercury (Hg) and zinc (Zn). (Wuana, 2011)

Prasad (2016) compiled a number of plants which were analysed in terms of phyto-remediation and phyto-stabilization of heavy metals contaminated sites which included: *Althea Althaea rosea*, *Amaranthus hypochondriacus*, *Antirrhinum majus*, *Calendula alata*, *Calendula officinalis*, *Celosia cristata*, *Chrysanthemum indicum*, *Chrysantemum maximum*, *Cosmos sulphureus*, *Erica andevalensis*, *Gladiolus grandiflorus*, *Helianthus annuus*, *Impatiens balsamina*, *Impatiens walleriana*, *Lonicera japonica*, *Mirabilis jalapa*, *Nerium oleander*, *Panicum maximum*, *Quamoclit pennata*, *Ricinus communis*, *Salvia splendens*, *Tagetes erecta*, *Tagetes patula*,

Although most of the articles regarding the use of ornamental plants for heavy metal phytoremediation envisaged their potential to accumulate heavy metals, little concern was provided to the efficiency of such measures which leads to the following questions:

- Does the dimension and the development of the root and shoot system of a plant have any influence on improving the heavy metal extraction from soil?
- Does the type of soil have any influence on the heavy metal uptake by plants?

In an extensive bibliographic study developed by Los Alamos National Laboratory, determined the mean ratios for depth, shoot height and radial lateral root spread, after analysing 392 deciduous trees, 17 evergreen trees, 15 shrubs, 10 grasses, 170 forbs and 12 subshrubs. The results were presented as ratios of depth (d) to shoot height (h), depth to lateral spread (ls) and lateral spread to shoot height (Table 1). (Foxx, 1984)

Considering the approximately maximum height of each plant as reported in the specialty literature and the ratios provided in Table 1, it is possible to determine the maximum depth and the radial lateral spread of the roots, thus enabling determination of the area for decontamination potential.

Table 1. Mean ratios for depth. Shoot height and radial lateral spread (Foxx, 1984)

Vegetation	no. of samples	d/h	d/ls	ls/h
Deciduous trees	392	0.42	0.36	1.39
Evergreen trees	17	0.57	0.64	1.2
Shrubs	15	1.2	0.85	2.5
Grasses	10	2.0	1.8	2.7
Forbs	34	1.7	-	2.0
	136	-	2.3	-
Subshrubs	12	-	4.4	-

Table 2 below includes the reported height of several ornamental plants as reported in the referenced articles. The depth (d) and the lateral spreading (ls) of the roots, were based on the coefficients provided in Table 1 by applying the following formulas:

$$d = h \cdot C_{d/h} \quad \text{and} \quad l_s = h \cdot C_{ls/h}$$

Where: d is the depth [L], h is the height [L], l_s is the lateral spread, $C_{d/h}$ is the mean ratio of depth and height and $C_{ls/h}$ is the mean ratio of lateral spread and height.

Table 2. Reported shoot height and calculated depth and lateral spread of roots

Species	Cat.	h [m]	d [m]	ls [m]	Reference for height
Althaea rosea	Shrub	2.0	2.4	5	Fahamiya, 2016
Antirrhinum majus	Forb	0.8	1.36	1.6	Bhargava, 2014
Calendula officinalis	Forb	0.3	0.51	0.6	Kareem, 2014
Celosia cristata	Forb	0.25	0.425	0.5	Miano, 2017
Chrysanthemum indicum	Forb	0.7	1.19	1.4	Ivanova, 1998
Chrysantemum maximum	Forb	0.7	1.19	1.4	Jamal Uddin, 2015
Cosmos sulphureus	Forb	1.0	1.7	2	Kumari, 2012
Erica andevalensis	Forb	1.5	2.55	3	Vecino-Bueno, 2009
Gladiolus grandiflorus	Forb	1.1	1.87	2.2	Adil, 2013
Helianthus annuus	Shrub	1.9	2.28	4.75	Buriro, 2015
Impatiens balsamina	Forb	0.8	1.36	1.6	Pal, 2018
Mirabilis jalapa	Forb	1.0	1.7	2	Singh, 2012
Panicum maximum	Grass	0.15	0.3	0.41	Nnadi, 2015
Ricinus communis	Shrub	2.0	2.4	5	Oliveira, 2017
Salvia splendens	Forb	0.3	0.51	0.6	Blazewicz-Wozniak, 2011
Tagetes erecta	Forb	0.4	0.68	0.8	Ul Haq, 2016

Based on the table above, it may be observed that the maximum depth of the roots are 2.55 m for a full grown *Erica andevalensis* and the maximum lateral spread is 5 meters for a full grown *Althaea rosea,* depicted in the pictures below.

Figure 2. *Althaea rosea*
(Source: https://worldoffloweringplants.com)

Figure 3. *Erica andevalensis* (source: http://fotopopular.com/smf2/index.php?topic=48037.0)

CONCLUSIONS

Most of the studies regarding phytoremediation are mostly dealing with the resilience of the plants to various contaminants rather than defining the limits in which plants may be used for contaminated sites. It may be concluded that smaller height plants are suitable for near surface contamination while higher plants may be used for deeper contamination. High attention should also be provided to the contamination hot spots and to the extent of the contamination related to the depth when selecting ornamental plants. A full environmental assessment is necessary for identifying soil types, contaminant concentration and extent, contaminant fate and transport characteristics and the future use of the site.

The adsorption potential in plants is a highly valuable information in the decision-making process but it should not be applied if the information mentioned above is insufficient. Several examples of risks include the usage of insufficient plants to cover the entire contaminant plume or usage of plants with small depth roots which do not reach the contaminant, but also other risks including high hydraulic conductivity of soil exceeding the adsorption potential of plants thus enabling the vertical contaminant migration.

The growth of each plant should be carefully taken into consideration in further research as it is necessary to determine the concentration reduction in soils, process efficiency as compared to the vertical migration of contaminants in the vadose zone and to identify the types of soil which may improve phytoremediation efficiency due to increased adsorption phenomena in plants.

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