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PHYTOREMEDIATION PLANNING IN THE CASE OF FORMER INDUSTRIAL SITES

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ABSTRACT. Contaminated soils from former industrial sites need urgent measures of treatment in order to be used for other purposes. Because of the large spaces that industrial sites usually occupy, green technologies have to be chosen to treat the soil while protecting the environment. Phytoremediation is an environmentally friendly technology that uses plants to decontaminate soils. The main advantage is the low cost compared to other techniques and the main disadvantage is the time factor because phytoremediation requires long period of time to treat the polluted soil. This paper presents specific features that must be taken into consideration when planning and implementing phytoremediation projects. Pollutants concentration and soil properties limit the application of phytoremediation. A clean-up plan is prepared taking into consideration limiting factors and then the remediation measures are implemented. The project needs long-term monitoring to determine the quantity of contaminants in soils during its implementation. The main purpose is to provide a safe environment for humans' health while improving the ecological situation of the former industrial sites.

Key words: *phytoremediation, planning process, former industrial sites, soil contamination*

INTRODUCTION

The population of the world is increasing and more and more land is required in the urbanization process. This has a detrimental impact on the expansion into the wilderness, forests and agricultural lands, so treating and using contaminated sites must play an important role in ensuring a sustainable development. Soil as a non-renewable resource represents a valuable asset and its clean-up in polluted areas can support biodiversity and create new ecosystems (Macek et al., 2002; Marcotullio et al. 2008; Zhang et al., 2011; Surriya et al., 2015).

Historically speaking, the industrial era meant the development of different branches of industry correlated with economic prosperity. After 1990, because of switching from manufacturing to services or because the industries moved to countries with lower labour costs, a lot of industrial sites were abandoned usually with a specific level of contamination. The redevelopment of formal industrial sites is necessary and some of the local authorities converted this type of sites for commercial, residential, industrial or even recreational functions (Loures and Panagopoulos, 2007).

Former industrial sites represent sources of contamination that can spread and affect the health of population. The routes of exposure are determined according to the site conditions (see figure 1).

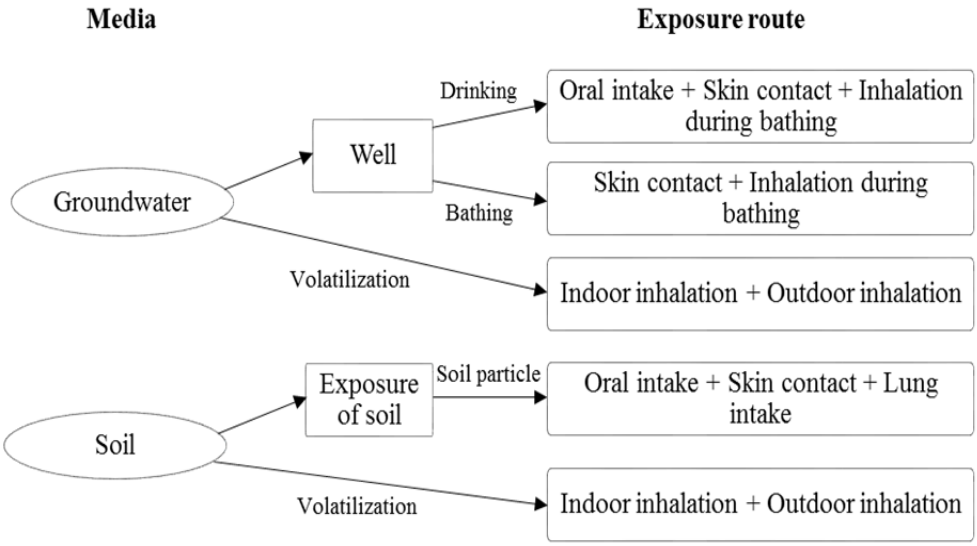

Fig. 1. *Exposure routes of dangerous compounds in the case of contaminated sites (Fujinaga, 2016)*

Contaminated sites can be treated using phytoremediation which is a technology that exploits plants to remediate dangerous compounds (Simeonova and Simeonov, 2006). Depending on the method and the remediation purposes, phytoremediation has been categorized into phytoextraction, phytodegradation, phytostabilization, phytovolatilization, rhizofiltration, rhizodegradation (EPA, 2001; Kvesitadze et al., 2006; Ali et al., 2013; Boroș and Micle, 2014; Filippis, 2015).

The aim of this paper is to present the most important factors that must be taken into consideration for the planning process of treating contaminated sites using phytoremediation. Former industrial sites can be integrated completely in the landscape after a well-documented evaluation of the present situation and the study of the most appropriate method.

LIMITING FACTORS IN IMPLEMENTING PHYTOREMEDIATION

The application of phytoremediation is not generally applicable because the conditions are different from case to case. So it is difficult to draw up a project plan that can be applied to more than one site. Every plan has to be designed for a specific case study and adapted to the local requirements for the best integration of the entire contaminated area (EPA, 2008).

In order to study the contaminated sites, three phases of diagnostic assessment procedure were identified. In the first phase, a preliminary site assessment is made which includes the site inspection and collection of data regarding maps, photos, literature, reports, articles etc. The second phase represents the comprehensive site assessment and implies sampling and analysis of media of interest to determine the exact contamination. The investigation and implementation of remedial measures are part of the third phase when the contamination is studied in detail and the plan and its actions are applied (Asante-Duah, 1995).

Former industrial sites are usually located in the vicinity of city centre or in the outskirts with good infrastructure which is an important advantage for stakeholders. They can decide to invest in the remediation process or not, depending on how huge the expenses are and how big the profit can be, according to the A-B-C model. Type A of economic opportunity states that the private sector can finance totally the reclamation of the land and the treatment of it if a safe profit is assured. A public-private cooperation can be necessary to implement the redevelopment of a polluted area in order to increase the value of the site and make profit (type B). Usually if the costs of site rehabilitation are very high, only the public sector invests in this case and only if it is for the public benefit (type C) (CARBERNET, 2006).

There are many parameters that must be taken into consideration when phytoremediation is applied at full-scale. Some of them are related to soil properties like texture, organic matter and pH and also to soil protection. An important issue is the contaminants' type and composition, which is relevant further in the process of selecting the most adequate plants. Another decisive element is the future use of land which determines directly the method that is applied on site and how intensive the remediation must be. The equipment that is used, the safety environment for workers, monitoring of the area, period and costs of remediation and also the inhabitants involvement are factors that cannot be neglected. In order to evaluate the feasibility of phytoremediation, a summary of these important parameters is presented in table 1.

Table 1. *Factors that limit the implementation of phytoremediation plan at field scale (after EPA, 2000; Mudgal et al., 2010; Meuser, 2013)*

Planning factor	Criteria	Evaluation of technical feasibility
Soil properties	Texture	Medium to fine sand, loamy sand, sandy loam and sandy clay loam soils are recommended and offer a high efficiency; Gravel, coarse sand and cohesive soils have limited applications

Planning factor	Criteria	Evaluation of technical feasibility
	Organic matter content	The best treatable concentration is 1 – 5 %; Concentrations less than 1 % and peaty soils offer strong limitations; High humus content of more than 5 – 30 % is less favorable
	pH value	Phytodegradation is not recommended in acidified soils, but is highly recommended for phytoextraction (pH <5,5); Soils with a pH of 5,5 – 7,5 are well treatable in the case of phytovolatilisation and rather not recommended for phytoextraction; Alkaline soils offer strong limitations (pH > 7,5)
Soil protection	Structure	Phytoremdiation has no negative impact on soil; Offers improvement of nutrient capacity, organic matter content and edaphon; Reduces impact on horizonation; Soil conditions can be improved by adding fertilizers
	Biological activity	
	Nutrients	
	Humus content	
Level of contamination	Scientific investigation methods	Cd, Cu, Ni, Pb, Zn are treatable by phytovolatilisation; Cd, Ni and Zn are pollutants preferred in phytoextraction; Cr and As treatment is restricted; Treatment of Hg is limited; Phytoextraction presents a low solubility of the organic pollutants; Phytodegradation can be used to treat organic pollutants like TPH, BTEX, Phenols, VCHC, PAH, PCB and free cyanides
	Type of pollutants	
	Pollutants concentration	
Sensitivity of the land use in future	Highly sensitive	The future use of the land is highly important to establish the remediation strategy; As a general rule, the higher the sensitivity of the land is required, the more intensive has to be the applied the remediation technique
	Sensitive	
	Low sensitive	
	Non-sensitive	
Plant selection	Type and depth of roots	For a proper selection of plants, lots of information must be gathered to choose the best characteristics of a plant for the specific site, climate, soil, pollutant, costs and biomass depending on the designed objectives
	Plant growth rate	
	Transpiration rate	
	Seed and plant source	
	Type of plant	
Time	Schedule	It requires longer remediation period than other techniques, even decades; The remediation plan should follow a step-by-step schedule with complete details about the processes and operation charts.
Costs	Mass to be treated	Costs can reach 25 – 50 € m^{-3}, exceptionally > 50 – 75 € m^{-3}
	Materials needed	
	Chosen method	
Long-term monitoring	Sampling procedures	Sampling and analyzing plants, soil, groundwater and vapors is part of the cleaning strategy
	Analyses	
	Immision control	

Planning factor	Criteria	Evaluation of technical feasibility
Citizens involvement	Raising awareness	The plan should involve the inhabitants from the beginning of the process; An advisory council can be established to hold meetings where the opinion of the members should be taken into consideration
	Presenting information	
	Participation in council meetings and decisions	
Equipment	Operating	The clean-up plan requires different type of equipment and trained personnel
	Maintenance	
Working safety	Sources of danger to human health	Special attention is needed for mechanical and chemical hazards; Ruined building can collapse; Chemicals can penetrate skin and be absorbed into the organism, there is also danger of asphyxiation and oral ingestion/inhalation; Fire and explosion are present risks on site
	Safety measures	A health and safety plan is developed prior to starting the remediation process

It is very important to monitor the plans that have been developed for soil treatment. Periodic monitoring is necessary to ensure optimization of remediation process and it is very important to record the decrease in concentration of constituents and also the quality of groundwater (Kondolf and Micheli, 1995; Finger et al., 2007).

Local communities need to be involved in every important step that is part of the redevelopment project. The success of the programme can be associated with the public participation and the future use of the area. In this way, the conflicts and the refuse of area rehabilitation generated by the noise, vibration due to the equipment used, dust created during the process and other unpleasant activities, are removed. The whole area is accepted easily by the citizens and represents a reference area of local identity (Soesilo and Wilson, 1997; ITRC, 2006).

PLANNING PHYTOREMEDIATION

One of the easiest ways to have best results in the phytoremediation plan is to prepare a detailed programme for the contaminated site. It should contain a list of all the information which has to be collected and all analytical tests, methods and research techniques that will be used. The site remediation program consists of several parts and includes health and safety of staff on site, staff requirements, equipment used, preservation of collected samples and analytical techniques. Remedial program also includes a presentation of the chosen method with the complete motivation for its choice. When it is necessary, standard procedures must be establish, otherwise, the documentation of the whole plan should not be unreasonably long (Russell, 2012).

It is important to plan carefully the phytoremediation studies and the soil treatment. Successive stages of phytoremediation planning and implementation are presented in figure 2.

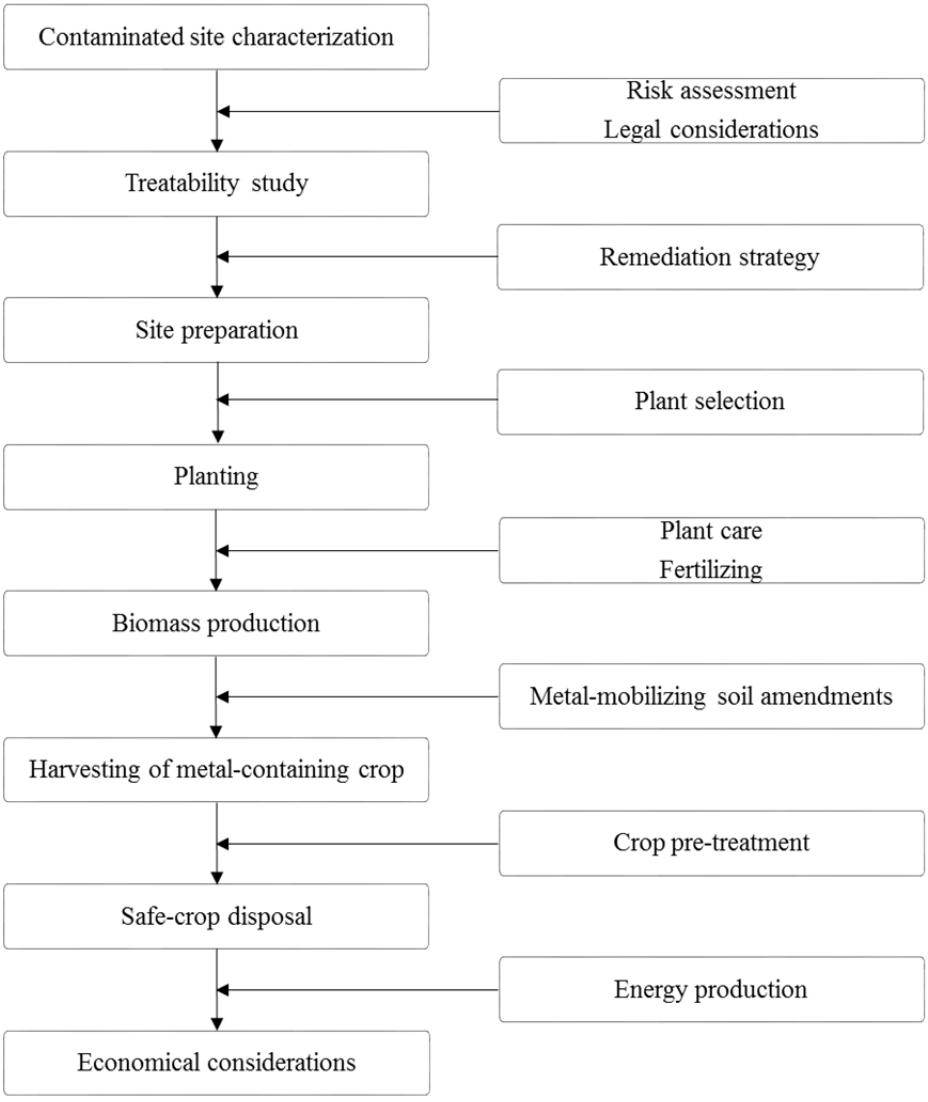

Fig. 2. *Scheme of the phytoremediation programme plan (after Sas-Nowosielska et al., 2005; Ibrahim et al., 2015)*

Site remediation cannot be carried on if the initial information is not obtained. The following details and documents have to be obtained in order to decide on the methods and proper solutions that can be implemented on site (Russell, 2012):

- Introduction and objectives;
- Site description, location and maps;
- Historical information;
- Information about the surface soil;
- Geological information, including national and local information about geological exploration;
- Utilities on site - streets, sewer, electric lines, buried water pipes, gas pipelines and telephone lines;
- Site maps and photos - including aerial photos, zoning and maps of property, where it is the case;
- Research plan of the site;
- Sampling plan - how many and which type of samples will be collected;
- Plan analysis - how samples should be preserved, handled, stored and analysed;
- Safety and health plan for staff on site, which includes information on exposure to contaminants while performing the necessary tasks.

The former industrial sites redevelopment can integrate landscape design in order to integrate parks in the scenario. The advantage of planning the future landscape concept is that it protects the valuable existing vegetation and increases biodiversity. These measures allow nature conservation and environmental protection for a sustainable development and increasing of quality of life in the surroundings.

On some of the contaminated sites, a mixture of wild plants grew, spreading on polluted soil and combined with the industrial ruined buildings and artefacts a special and unique landscape was created. In some of the places, architects, town planners and artists were interests in this type of scenery and identified new symbols for human history and industrial value. Their alternative in site redevelopment is to leave some areas in their actual state in order to permit natural succession of species so that artistic monuments can be created (USEPA, 2010).

CONCLUSIONS

Former industrial sites that are contaminated with various types of pollutants can be treated using green technologies like phytoremediation. Even though it is a technique that needs a long period to remediate the area, it is well accepted by the public that can take benefits from the site rehabilitation. Compared to other techniques, implementation of phytoremediation is cost-effective, which is a great advantage when there are very large areas that need remediation.

The entire phytoremediation design and implementation at full scale is a well-documented process and requires an evaluation of technical feasibility. Planning phytoremediation should take into consideration many factors that are

decisive in the efficiency of the implemented solution. To control the spread of contamination, but also to record the progress of remediation, a long-term monitoring must be prepared in detail.

Because the application of phytoremediation is a site-specific process, standard procedures cannot be establish, but the general guidelines can be taken into consideration for every location and every step has to be particularized.

The main objective of every site remediation is to improve the current situation of each contaminated area in order to provide a safe and healthy environment for every citizen.

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