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Review

Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: A review

Amanullah Mahar [a,b,1], Ping Wang [a,1], Amjad Ali [a], Mukesh Kumar Awasthi [a,c], Altaf Hussain Lahori [a], Quan Wang [a], Ronghua Li [a], Zengqiang Zhang [a,*]

[a] College of Natural Resources & Environment, Northwest A&F University, Yangling, Shaanxi 712100, China
[b] Centre for Environmental Sciences, University of Sindh, Jamshoro 76080, Pakistan
[c] Department of Biotechnology, Amicable Knowledge Solution University, Satna, India

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ABSTRACT

Mining operations, industrial production and domestic and agricultural use of metal and metal containing compound have resulted in the release of toxic metals into the environment. Metal pollution has serious implications for the human health and the environment. Few heavy metals are toxic and lethal in trace concentrations and can be teratogenic, mutagenic, endocrine disruptors while others can cause behavioral and neurological disorders among infants and children. Therefore, remediation of heavy metals contaminated soil could be the only effective option to reduce the negative effects on ecosystem health. Thus, keeping in view the above facts, an attempt has been made in this article to review the current status, challenges and opportunities in the phytoremediation for remediating heavy metals from contaminated soils. The prime focus is given to phytoextraction and phytostabilization as the most promising and alternative methods for soil reclamation.

Contents

1. Introduction

Heavy metal contaminated soil is a serious concern in most countries. Ecological rehabilitation of the contaminated soils in the industrial, agricultural, and urban territories (Fig. 1) is a great challenge in recent decades due to anthropogenic activities (Wang et al., 2014; Li et al., 2015; Mahar et al., 2015; Xiao et al., 2015).

One-sixth of the total agricultural land area in China has been contaminated with heavy metals, and approximately 40% has been reported to be disturbed by erosion and rapid deforestation (Liu et al., 2005; Convard et al., 2005). In China, heavy metals in 16.1% farmland soils have exceeded the environmental quality standard for soil. For agricultural soils the percentage of exceedance was even greater at 19.4%. Among heavy metals and metalloids, Cd ranks first in the percentage of soil samples (7.0%) exceeding the standard limit in China (Environmental Protection Ministry, 2015;

* Corresponding author.
E-mail address: zhangzq58@126.com (Z. Zhang).
[1] First two authors contributed equally.

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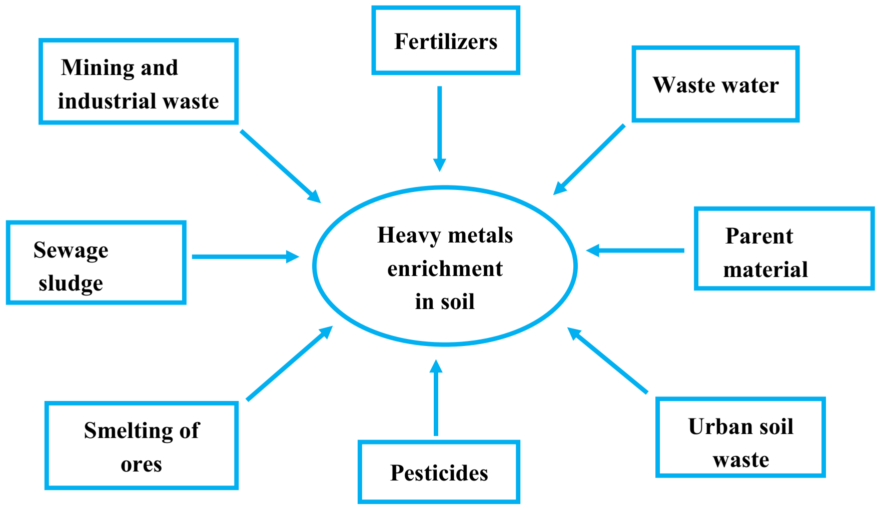

Fig. 1. Major sources of heavy metals in soil.

Luo et al., 2009). Soil contamination is also an important issue across the European Union (EU). About 3.5 million sites in the EU were estimated to be potentially contaminated with 0.5 million sites being highly contaminated and needing remediation. There are 400,000 polluted sites in the European countries including Germany, England, Denmark, Spain, Italy, Netherlands and Finland. Sweden, France, Hungary, Slovakia and Austria have less number of 200,000 contaminated sites. Greece and Poland reported 10,000 contaminated land areas, while Ireland and Portugal reported fewer than 10,000 contaminated sites (Perez, 2012). In America, approximately 600,000 ha brown field sites have been polluted with heavy metals (De Sousa and Ghoshal, 2012; Orooj et al., 2015).

Technical and financial implications have made soil remediation a difficult task (Barcelo and Poschenrieder, 2003). Over the last 20 years several biological, physical and chemical approaches have been used to achieve this goal (Sheoran et al., 2011; Wuana and Okieimen, 2011). Generally, these approaches have limitations i.e. intensive labor, high cost, disturbance of indigenous soil microflora and irreversible changes in soil physicochemical properties. Among the different approaches to the restoration of heavy metals contaminated soils in situ, special attention is drawn to the technologies of phytoremediation (green and clean technologies). The term phytoremediation was formed by phyto (Greek phyton: related to plant) and remedium, which means to cleanup. Phytoremediation is based on the use of natural or genetically modified plants capable of extracting hazardous substances i.e. heavy metals including radionuclides, pesticides, polychlorinated biphenyls and polynuclear aromatic hydrocarbons from the environment and turning them into safe compounds metabolites (Clemens, 2001; Suresh and Ravishankar, 2004; LeDuc and Terry, 2005; Chehregani and Malayeri, 2007; Odjegba and Fasidi, 2007; Turan and Esringu, 2007; Lone et al., 2008; Kawahigashi, 2009; Saier and Trevors, 2010; Kalve et al., 2011; Sarma, 2011; Singh and Prasad, 2011; Vithanage et al., 2012; Bolan et al., 2014a; Greipsson, 2011).

Based on economic implications, the aim of phytoremediation can be three layered: (1) plant-based extraction of metals with financial benefit i.e. Ni, Tl; (2) risk minimization (phytostabilization); and (3) sustainable soil management in which phytoremediation steadily increases soil fertility allowing for follow up crop growth with added economic value (Vangronsveld et al., 2009; Garbisu and Alkorta, 2003; Van Aken, 2009). In addition, high-biomass production and rapid growing plants such as tree species i.e. poplar, jatropha and willow are being exploited for the dual purpose of energy production and phytoremediation (Abhilash et al., 2012; Prasad, 2003; Chaudhry et al., 1998; Chaney, 1983; Pilon-Smits, 2005).

The modern technologies of phytoremediation are based on different uptake mechanisms (Fig. 2) which include

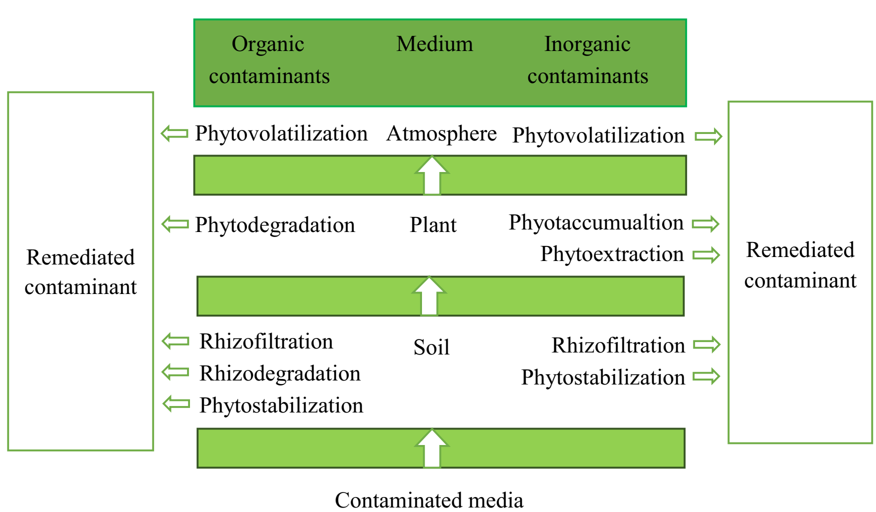

Fig. 2. Uptake mechanisms of phytoremediation technology.