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An overview of heavy metal stress in soil ecosystem and technological intervention for its remediation

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Abstract

With the advent of industrialization and modernization in agriculture to feed the increasing population, there has been negative effect on environment and human health. Among all kinds of pollution, heavy metal pollution is significant in soil ecosytem and are hazardous contaminants of environment, which pose detrimental effect on human health and listed as priority pollutants by United State Environmental Protection Agency (USEPA). Lead (Pb), Mercury (Hg), Arsenic (As) and Cadmium (Cd) are ranked 1st, 2nd, 3rd and 6th respectively in the list of US agency for toxic substances and disease registry. Concentrations of these toxicants in human and animal body increases many fold through bio magnification and causes serious health problems in human viz. biological defenses, intrauterine growth retardation, impaired psychosocial faculties, disabilities associated with malnutrition, decreased immunity and high prevalence of upper gastrointestinal cancer. Thus, there is an urgent need of preventive and/or curative measures to decrease the flow of heavy metals in food chain of human beings. But, the process of modernization and industrialization could not be avoided as they are integral part of development. Therefore, we have to think for sustainable way to reduce the impact of these heavy metals on environment and in this process, there are various technological intervention such as use of natural sorbents e.g. vermicompost, sawdust, farm yard manure; phytoremediation process by using hyperaccumulator plants; use of chelating agents that binds with heavy metal owing to property of chelation; biotechnological tools and recently developed nanotechnology which has exceptional adsorption and high surface area unique mechanical and electrical property with high chemical stability which is attracting attention of research for remediation of heavy metals from contaminated ecosystem. Objective of this paper is to briefly overview the heavy metal stress in soil ecosystem, their possible sources, movement through food chain and sustainable remediation strategies.

Keywords: Heavy metal, soil ecosystem, remediation, biomagnification, natural sorbents, phytoremediation, chelation, nanotechnology.

Introduction

With the advent of industrialization and modernisation in agriculture, there has been a considerable increase in the discharge of waste to the environment, chiefly soil and water, leads to deterioration of environmental health (Toth *et al*., 2016; Rai, 2018a) [83, 92]. Among all kinds of pollution, heavy metals pollution is one of the serious environmental pollution and emerging as a matter of concern at local, regional and global scales (Nedel-Koska and Doran 2000) [42]. Heavy metals are listed as priority pollutants by the United States Environmental Protection Agency (USEPA, 2000) [89]. Depletion of heavy metals takes place in soil system through leaching, plant uptake, erosion and deflation, but it is very slow process and the problem of heavy metal pollution is very worrying due to its toxicity to plants, animals and humans and their lack of biodegradability (Wuana and Okieimen, 2011) [85]. As per the Indian standard, the permissible limit of Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Arsenic (As) in food is 1.5, 20, 30, 1.5, 2.5 and 1.1 mg kg^{-1} respectively whereas permissible limit of Cd, Cu, Pb & Ni in soil ranges between 3-6, 135-270, 250-500 and 75-150 mg kg^{-1} respectively and the permissible limits of lead and cadmium in drinking water are only 0.1 and 0.005 mg L^{-1} respectively, however, the actual concentrations of these elements in drinking water are in between 0.02 - 0.215 and 0.01 - 0.11 mg L^{-1} respectively, which is proving fatal for living organisms (Awasthi, 2000) [5]. Excess heavy metal concentrations have a negative effect on the metabolic activities of the plants and therefore have a quantitative and qualitative effect on food production as well as long-lasting effects on the ecosystem. Globally, seventy thousands chemicals are in use (Cairns *et al*. 1988) [9]. For the level of toxicity, lead, mercury, arsenic and cadmium are ranked first, second, third, and sixth, respectively, in the list of US Agency for Toxic Substances and Disease Registry (ATSDR) (Rai, 2018a) [92]. Many of them are toxic even at very low concentrations; arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc *etc*. and are not only cytotoxic but also carcinogenic and mutagenic in nature (Arora *et al*., 2008) [4].

The problem of heavy metal pollution is continuously increasing due to a series of human activities, leading to an intensification of research dealing with the phytotoxicity of these contaminants and mechanisms by which plants counter their detrimental effects (Rascio and Navari-Izzo, 2011) [54]. Living organisms require varying amounts of few heavy metals like Iron, cobalt, copper, manganese, molybdenum and zinc are required by humans in trace amounts (Singh *et al*., 2011) [75] and beneficial at low concentrations by improving plant growth and yield (Imran *et al*., 2016b). But higher concentrations of these metals not only exert damaging effects on plant health but could have deleterious potential to other organisms including human (Roy and McDonald, 2013) [59]. Heavy metals affect various physiological and biochemical processes in plant and could inhibit plant growth and cell death to critical level (Popova *et al*., 2009; Xu *et al*., 2009) [46, 86]. This growth reduction might be explained on the basis of decreased photosynthetic rate and chlorophyll content. Heavy metal toxicity could cause cell membrane damage and destruction of biomolecules and cellular organelles due to increase in the production of reactive oxygen species (ROS) in plants under stress (Singh and Prasad, 2015) [72].

The entry of heavy metals in the food chain is of special concern due to a number of associated health risks in animals and human. These elements are very toxic and have potential to cause severe damages even at very low concentrations (Sarwar *et al*., 2010) [62]. Excess accumulation of heavy metals disrupts the function of vital organs and glands such as heart, brain, kidneys, bone, liver, etc. along with disruption of metabolic functions in human beings. These metals displace the vital nutritional minerals from their original place and hinder their biological function. These metals can enter into our body through consumption of foods, beverages, skin exposure and inhaled air. Among different heavy metals, chronic exposure to low doses of cancer-causing heavy metals may induce many types of cancer. Park *et al*. (2004) [43] found an increased lifetime risk of lung cancer death resulted from occupational exposure to dusts and mists containing hexavalent chromium. Acute and chronic exposure of arsenic could also cause numerous human health problems. These included dermal, respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, neurological, developmental, reproductive, immunological, genotoxic, mutagenic and carcinogenic effects (Lin *et al*. 2013) [30].

Thus, there is dire need of several management practices to minimize metal toxicity. There are many traditional methods available, but are either extremely costly or they are simply applied to isolate contaminated site. So, there is a need of technology to clean environment up to safer limit with suitable techniques, which must be easy to handle, cost-effective and feasible. Common approches for remediation of metal contamination include isolation, immobilization, toxicity reduction, physical separation and extraction. These general approaches can be used for many types of contaminants but the specific technology selected for treatment of a metals contaminated site will depend on form of the contamination and other site-specific characteristics. The use of technology like use of hypermetal accumulator plants occurring naturally or created by transgenic technology, nanotechnology, use of natural materials like vermicompost, saw dust etc. as well as chelating agent in recent years draws great attention to remediate heavy metal contamination. Thus, this review briefly deals with movement of different heavy metal in soil ecosystem and food chain and sustainable management approaches to reduce heavy metal contamination in soil.

2. Heavy metal Pollution in soil ecosystem

2.1 Sources

Heavy metals occur in soil environment either through natural or anthropogenic process. The natural sources of heavy metal pollution in soil constitute mainly of weathering of rocks and of little forest fires and volcanic eruption. During pedogenetic processes of weathering of parent materials, heavy metals are released in trace (<1000mg kg^{-1}) and are rarely toxic (Pendias, 2001) [27]. Due to the disturbance and acceleration of nature’s slowly occurring geochemical cycle of metals by anthropogenic actions, most soils may accumulate one or more of the heavy metals above defined background values high enough to cause risks to human health, plants, animals and whole ecosystems. The Heavy metals in the soil from anthropogenic sources tend to be more mobile, hence bioavailable than pedogenic, or lithogenic ones (Kaasalainen and Halla, 2003) [26]. Heavy metals at contaminated sites can originate from a wide variety of anthropogenic sources such as application of chemical fertilizers and pesticides in crop production, use of biosolids (sewage sludge), compost, metal mine tailings, disposal of high metal wastes in improperly protected landfills, leaded gasoline and lead based paints, coal combustion residues, petrochemicals, and atmospheric depositionm (Woldetsadik *et al*., 2017; El-Kady and Abdel-Wahhab, 2018) [84, 14]. The important sources of heavy metal contamination and its fate is given in figure 1.

Agriculture has the first major human influence on the soil (Scragg, 2006) [66]. For completion of life cycle of a plant, along with macronutrients (N, P, K, S, Ca, Mg), there is need of micronutrients such as Co, Cu, Fe, Mn, Mo, Ni, and Zn. Chemical fertilizers are applied to soils in intensive farming systems to provide adequate N, P, and K for crop growth but these fertilizers contains traces of heavy metals (e.g., Cd and Pb) as impurities, which, after continued fertilizer application may significantly increase content of heavy metal in the soil (Jones and Jarvis, 1981) [24]. Metals like Cd and Pb, have no role in physiological activity of plant but, during application of certain phosphatic fertilizers, Cd and other potentially toxic elements are added to the soil, including F, Hg, and Pb which cause toxic effect in plant (Raven *et al*., 1998) [57].

Pesticides is another potent sources of heavy metals in soil and are used extensively in agriculture and horticulture. Very common pesticides such as *Bordeaux mixture* (copper sulphate) and copper oxychloride are used widely which are copper containing fingicides. Compared with fertilizers, the use of pesticides more localized, being restricted to particular sites or crops (Mclaughlin *et al*., 2000) [38].

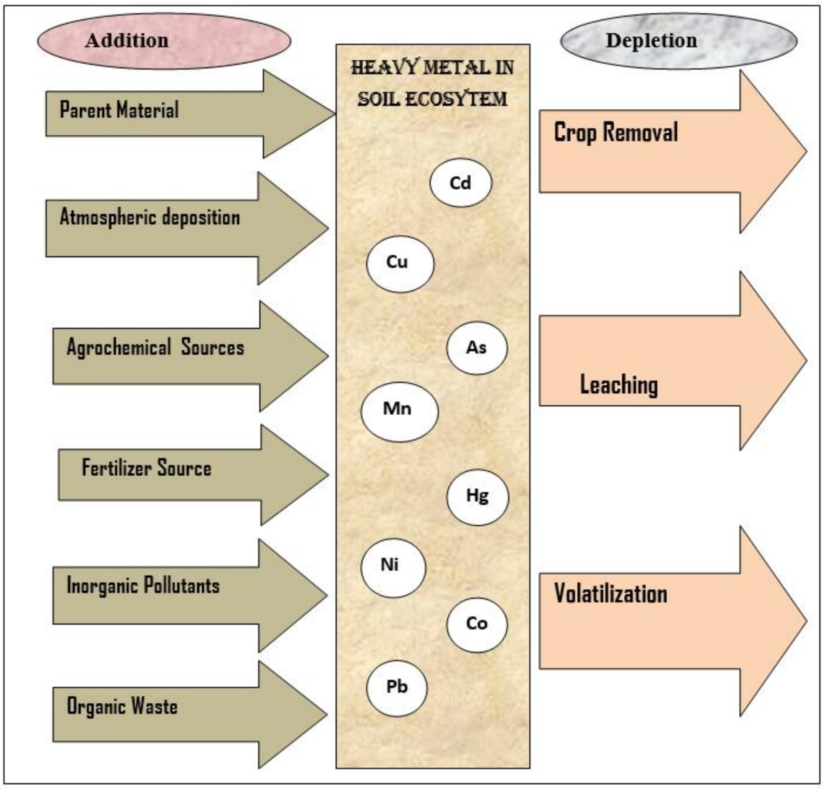

Fig 1: Sources of heavy metal pollution in soil (Adapted from Wuana and Okieimen, 2011) [85]

The blind application of number of biosolids such as livestock manures, composts, and municipal sewage sludge to soil system leads to the accumulation of heavy metals such as As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Mo, Zn, Tl, Sb, and so forth, in the soil (Basta *et al*., 2005; Ram Chandra and Kumar, 2017) [8]. Animal wastes such as poultry, cattle, and pig manures are produced in agriculture and commonly applied to crops and pastures either as solids or slurries. Although most manures are used as fertilizers, but, in the pig and poultry industry, Cu and Zn added to diets as growth promoters and As contained in poultry health products have the potential to cause metal contamination of the soil (Sumner, 2000) [78]. The manures produced from such animals contains high concentrations of As, Cu, and Zn. Biosolids or sewage sludge are produced in waste water treatment processes where organic solid product is obtained after recycling of water. But, these biosolids may contains heavy metal in it and have potential for contaminating soils and has caused great concern about their application in agricultural practices. Heavy metals most commonly found in biosolids are Pb, Ni, Cd, Cr, Cu, and Zn, and the concentration of metals in these biosolids are decided by the nature and the intensity of the industrial activity and the type of process employed during the biosolids treatment (Mattigod and Page, 1983) [35]. Under certain conditions, metals added to soils in applications of biosolids can be leached downwards through the soil profile and can have the potential to contaminate groundwater (McLaren *et al*., 2005) [37].

2.2 Heavy metal contamination from soil system to food chain

From soil ecosystem, heavy metals move to plant and ultimately to animals and human being. When heavy metals move to the higher trophic level in food chain, due to the non-degradability of heavy metals, they accumulate in the living system and passes to next trophic level as such with increased concentration and the process is known as biomagnification and accumulation of heavy metals in living system is known as bioaccumulation. Heavy metals from soil also leached down to the ground water reservoirs making it unfit for drinking purpose by contaminating it. The movement of heavy metal in soil, water and living organism is given in figure 2. Schreck *et al*. (2012, 2013, 2014) [63, 64, 65] conducted series of experiment on Pb uptake by *Lactuca sativa* and showed that foliar uptake of the heavy metal occurred mainly via adsorption to the cuticle or stomatal pores. Heavy metals are uptaken from the roots to the aerial parts of the plant by mechanism of xylem loading, while, foliar transport of heavy metals involves the phloem vascular system. With regard to the mechanisms of heavy metal uptake in crops, study of foliar translocation is less than the root uptake mechanism (Shahid *et al*., 2016) [68].

Detailed study on movement of heavy metals from soil to food crops showed that movement occurs through molecular homeostasis, physiological and biochemical alterations and intracellular compartmentalization (Clemens and Ma, 2016; Yang *et al*., 2018; Rai *et al*., 2019) [12, 88, 53]. Heavy metals can cause functional and structural membrane disintegration, damage to DNA strands and cause oxidative stress by generation of reactive oxygen species (ROS) which all ultimately increase the phytoavailability of heavy metals in crop plants (Rai *et al*., 2019) [53]. All these biochemical, physiological, and genetic changes in plants are invariably linked with human health and the food chain (Fig. 2). Heavy metals deteriorates the enzyme system (e.g., acid phosphatases, proteases, and α-amylases) and protein profiles involved in germination. For example, heavy metals toxicity stress in plant reduces the starch content, nutrient level, inhibits the photosystem-II (PS-II) of the chloroplast and induces the expression of heat shock proteins and proline (Rai, 2016a; Seneviratne *et al*., 2017) [51, 67]. Experiment showed that an increased level of metal contamination in certain vegetables (highest in water spinach, followed by amaranth, leaf mustard, Chinese flowering cabbage, green capsicum, and tomato) reduced their biomass and chlorophyll content; by contrast, the level of peroxidase, an anti-oxidative enzyme, initially showed increased level at low concentrations of the metallic contaminants (Rai *et al*., 2019) [53].

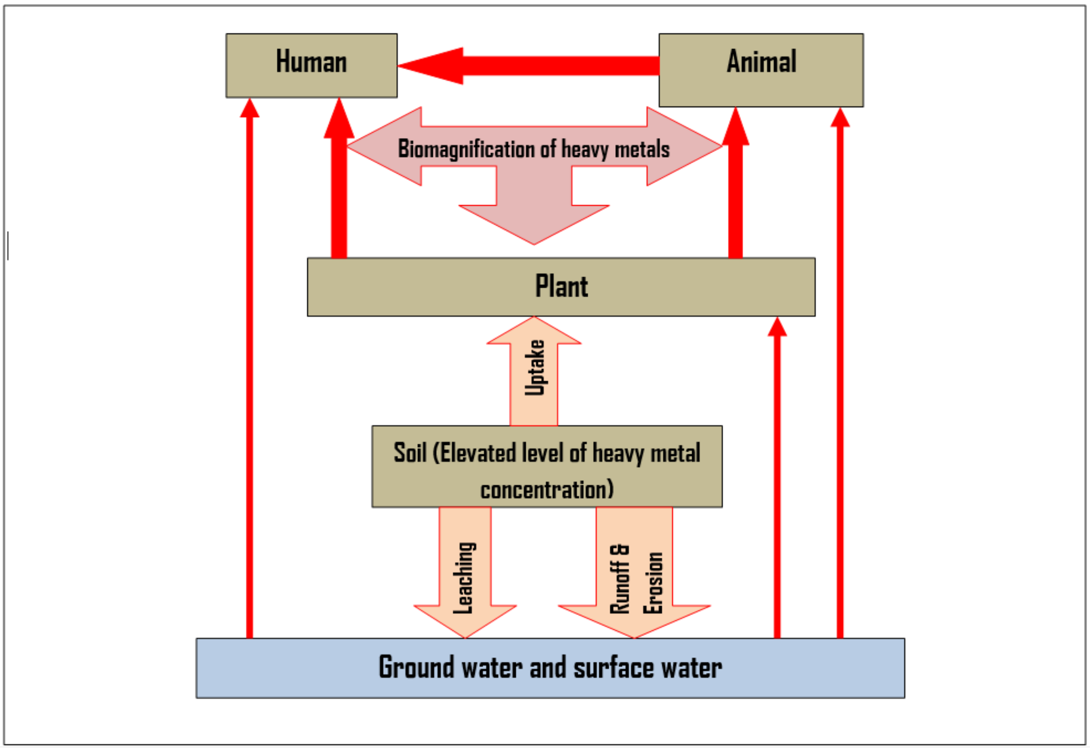

Fig 2: Heavy metal movement in soil, water and living organism through food chain and the process of biomagnification (Adapted from Singh and Prasad, 2015) [72]

3. Different interventions for remediation of heavy metals from soil ecosytem

3.1 Use of natural sorbents

Use of cost effective technique such as natural sorbents (farm yard manure, vermicompost, saw dust, rice husk) can be one of the potential measure, which can be effectively used in place of conventional expensive sorbents. Though, compost is considered to be source of heavy metal in soil, but if proper care is taken in using source material and method of composting, natural products like farm yard manure (FYM) and Vermicompost (VC), available from waste product, can be potentially used in combating heavy metal pollution in soil by the process of absorption and translocation of heavy metal in soil which is largely governed by organic subtances present in soil (Singh and Prasad, 2013a) [70]. Experiment by Angelova *et al*. (2010) [3] showed that concentration of lead (Pb) and copper (Cu) decreased in potato peel and tubers with 10 per cent compost or 10 per cent vermicompost amendment in soil. Jones and Healey (2010) [25] too found that heavy metals can be removed and stabilized by using compost, biosolids and recycled paper waste. Singh and Prasad (2014) observed that amendment with FYM, FYM+ NPK, sawdust and rice husk at 5 per cent dose significantly helps in reducing cadmium load in leafy vegetable (*Amaranthus caudatus*). FYM and vermicompost are richest source of cations and add Na, K, Ca and Fe to soil and increase organic matter content of soil which acts as primary sorbent of heavy metals in contaminated soil. The reactive group such as hydroxyl, phenoxyl and carboxyl in organic matter react with heavy metal to form stable complexes. Saw dust and rice husk can also act a binding agent of heavy metals due to their basic nature of complex compound i.e. cellulose, lignin, tannins etc. The lignin is known to interact with cations by exchanging with protons and subsequently by chelating with the metallic ions (Rafatullah *et al*., 2009) [48]. Lignin is the third major component of the wood cell wall and it is built up from the phenylpropane nucleus; an aromatic ring with a three carbon side chain, which is promptly available to interact with cationic metal ions (Fatemeh *et al*., 2008) [15]. Due to the low cost of natural sorbents, these materials at end of their lifetime can be disposed of in agricultural fields for metal remediation purposes. The abundance and availability of agricultural by-products make it good sources of raw materials for natural sorbents. The organic substance present in the soil has a significant impact on absorption and translocation of heavy metal (Cu, Zn, Pb and Cd) in soil and it turns into more stable forms and leads to accumulation of metals in organic horizons of soil and peat (Kabata-Pendias, 2001) [27]. Mineral amendments can be used in agriculture for remediation of heavy metal (Paulose *et al*., 2007) [45]. Bio-availability of metal ions in soils is largely governed by chemical equilibrium of metal ions in solid and solution phases, adsorption reactions are important to determine availability of metal to plants and their mobility throughout the soil. Singh and Prasad (2013b) [71] have also reported that application of natural products such as FYM, saw dust (SD) and rice husk (RH) in Cd-contaminated soil reduced the level of Cd by 36 % under FYM, 23 % under RH and 14 % under SD amended soil. Kalsi *et al*. (2016) [28] showed the impact of organic and inorganic amendments on Pb bioavailability and its immobilization in Indian mustard (*Brassica juncea* (L.) *Czern*) with five levels of Pb varying from 0 to 400 mg kg^{-1} soil using amendments ($CaCO_3$), farm yard manure (FYM) and press mud (PM) @ 2.5 and 5.0 per cent (w/w) and silt + clay applied at 20 and 40 per cent (w/w). Results reveals that all amendments reduced the extraction of

Pb as well as Pb accumulation by Indian mustard was also reduced and the magnitude of reduction increased with increasing the rate of amendment application.

3.2 Use of complexing agents or chelates

Chelates form complexes with the heavy metal cations and this property is used to remove toxic metals from soil solid phases. After complex formation, it can be removed from the soil by plants through enhanced phytoextraction or by using soil washing techniques. Chelant can desorb metals from the soil matrix, and the mobilized metals move to rhizosphere for uptake by plant roots in the process of phytoextraction (Tahmasbian and Sinegani, 2013) [79]. The amounts of bio-available metals in soil solution are mainly determined by the properties of the soil and applied chelant (Luo *et al*., 2005) [33]. Sukumara *et al*. (2012) [77] have observed that Ethylene Diamine Tetra Acetic acid (EDTA) is one of the most powerful and commonly used chelating agents, which forms complexes with many of metal contaminants within the natural environment. It was found that application of EDTA as chelating agent increases the efficiency of an emergent wetland plant species such as *Typha* sp. and floating wetland macrophytes like *Pistia* sp., *Azolla* sp., *Lemna* sp., *Salvinia* sp. and *Eichhornia* sp. in phytoremediation of lead and copper (Sukumara *et al*., 2012) [77]. Due to some undesirable property such as long persistence time or slow transformation of conventional complexing agents, there is need of chelating agents with improved biodegradability (Reinecke *et al*., 2000) [58]. Dede *et al*. (2012) [13] in an experiment to investigate the effect of chelating agent ethylenediaminetetraacetic acid (EDTA) on copper, zinc, nickel, cadmium, chromium and lead uptake by *Brassica juncea* from sewage sludge showed that applications of EDTA resulted in a considerable increase in copper and lead concentrations in the plant and reveals that EDTA can be used as effective amendment for phytoextraction of heavy metals from sewage sludge. Bahemmat *et al*. (2016) [7] investigate the role humic acids (HAs) and fulvic acids (FAs) as chelating agents in improving electrokinetic remediation efficiency of highly contaminated soil by applying a constant voltage of 2.0 volt/cm, pH and current changes to the soil and heavy metals concentration were investigated through a range of durations and positions and observations reveals that both catholyte conditioning with 0.1 N HNO_3 and using humic substances (HSs) showedd enhanced remediation efficiency. It was also shown that after 20 days of electrokinetic treatment, the removal efficiency of heavy metals in HS-enhanced emediation was about 2.0–3.0 times greater than when unenhanced and the quantity of heavy metals moving towards the cathode exceeded the anode, inferring that most negatively charged heavy metal-humic acid complexes were moved by electroosmotic forces. Tang *et al*. (2017) [80] conducted an experiment to explore the potentiality of an electrokinetic decontamination treatment of heavy metal removal by using a biodegradable complexing agent Tetrasodium of N, *N*-bis (carboxymethyl) glutamic acid (GLDA) along with combination of biodegradable biosurfactant (rhamnolipid) to decontaminate heavy metals from the sludge and shows that the use of GLDA as an electrolyte enhance the removal efficiencies of Cu, Zn, Cr, Pb, Ni and Mn by 53.2 ± 3.12%, 67.4 ± 3.45%, 59.2 ± 4.78%, 45.4 ± 4.15%, 72.8 ± 3.68% and 45.0 ± 4.85%, respectively when compared with deionized water, while, a further improvement in heavy metals removal efficiencies of Cu, Zn, Cr, Pb, Ni and Mn by 64.8 ± 2.34%, 56.8 ± 4.12%, 49.4 ± 4.45%, 46.6 ± 2.35%, 60.4 ± 3.45% and 69.6 ± 3.54%, respectively were achieved by repalcing rhamnolipid as the electrolyte. Significantly higher removal efficiencies of heavy metals were obtained by the simultaneous use of GLDA and rhamnolipid due to their synergic action in electrokinetic process.

3.3 Use of hyperaccumulator plants or phytoremediation

Phytoremediation is the bio-remediation process of using plants and associated soil microbes to reduce the concentrations or toxic effects of heavy metals contaminants in the polluted environments (Greipsson, 2011; Parmar and Singh, 2015) [18, 44]. It refers to the use of special type of plants to decontaminate soil or water by inactivating metals in the rhizosphere or translocating them in their aerial parts. Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Violaceae and Euphorbiaceae are the common families of plants showing remediation property (Sarma, 2011) [61]. It is a novel, cost-effective, efficient, environment and eco-friendly, in situ applicable, and solar-driven remediation strategy (Ali *et al*., 2013) [2]. Green plants have an enormous ability to uptake pollutants from the environment and accomplish their detoxification by various mechanisms such as phytoextraction, phytofiltration, phytostabilisation and phytovolatisation (Muthusaravanan *et al*., 2018) [40]. Chaney (1983) [11] gave the concept of phytoremediation (as phytoextraction). Phytoaccumulator plants have high tolerance level to heavy metals and more tendencies to accumulate metals in their shoots (Baker *et al*., 2000) [6] and most of the hyperaccumulator plants are slow growing and produce less biomass. The roots of Indian mustard are effective in removal of Cd, Cr, Cu, Ni, Pb and Zn (Prasad and Freitas, 2003) [47]. The hyperaccumulating ability of aquatic macrophytes *Azolla* is well known and can successfully is used for phytoremediation of heavy metals from soil and water. *Azolla* accumulate toxic elements viz. arsenic, mercury, cadmium, chromium, copper, nickel and zinc in its biomass by up taking them from soil and water bodies in which it is grown. Both, living and dead biomass of *Azolla* have been exploited for the removal of heavy metals from industrial effluents and sewage water. There is large variation in bioaccumulation potential of *Azolla* strains. *Azolla* Pinnata accumulates 667 µg Hg g^{-1}, 740 µg Cd g^{-1} (Rai, 2008) [49]; 1095 µg Cr g^{-1} (Rai, 2010b); 16252 µg Ni g^{-1} (Arora *et al*., 2004). Wuana and Okieimen (2010) have found that Zea mays (maize) is able to phytoextract the metals from contaminated soils. The soil quality can also be maintained by phytoextraction method. Jiang *et al*. (2010) [23] have shown that quality of soil (microbial biomass, basal respiration and enzymatic activities) is maintained by using successive cropping of hyperaccumulator plant *Sedum plumbizincicola* for two year period. Nayak *et al*. (2018) [41] conducted an experiment to assess the potential of rhizospheric bacteria in metal accumulation by the chromium hyperaccumulator *Vetiveria zizanoides.* The bacterial strain *Bacillus cereus* (T1B3) strain, isolated from mine tailings exhibited plant growth-promoting traits including, 1-aminocyclopropane-1-carboxylate deaminase, indole acetic acid, and siderophores production along with nitrogen fixation, and phosphorus solubilization and strain was able to remove (mg L^{-1}) 82% Cr^{+6} (100), 92% Fe (100), 67% Mn(50), 36% Zn (50), 31% Cd (30), 25% Cu (30), and 43% Ni (50) during the active growth cycle in heavy metals-amended, extract medium. Results also shows that inoculation of the native *V. zizanioides* with T1B3 strain helps in improving phytoremediation efficiency of heavy metals. The mechanism of plants involved in stabilization of heavy metals are that it should decrease the amount of water percolating through soil matrix and acts as a barrier to prevent direct contact with contaminated soil and should also prevent soil erosion and distribution of the toxic metal to other areas (Raskin and Ensley, 2000) [55]. Jadia and Fulekar (2008) [21] have observed that due to large surface area of fibrous roots of sorghum and intensive penetration of roots into the soil, it is capable of immobilizing and concentrating heavy metals in the roots by reducing leaching via stabilization of soil. Gong *et al*. (2018) [17] suggested the fate of accumulated heavy metals in plant for safe disposal and conducted an experiment to show effect of pyrolysis on the stabilization of heavy metals in plant residues obtained after phytoremediation. Ramie residue (residue collected after phytoremediation of metal contaminated sediments) were pyrolyzed at different temperatures (300–700 °C) and found that pyrolysis was effective in the stabilization of Cd, Cr, Zn, Cu, and Pb in ramie residues by converting the acid-soluble fraction of metals into residual form. Also, the pyrolysis products generated from ramie residues obtained after phytoremediation was reutilised as sorbents and has excellent capacity to adsorb methylene blue (MB) having maximum adsorption capacity of 259.27 mg g^{-1} and this study suggests that pyrolysis can be an efficient alternative method for stabilizing heavy metals in plant residues obtained after phytoremediation, and their pyrolysis products could be reutilized for dye adsorption.

3.4 Use of novel technique such as biotechnology and nanotechnology

Nanotechnology refers to technology in the particle size range of 1-100 nanometers comparable to typical bacterial cell which has a diameter of the order 1,000 nm and the application of nanotechnology for remediation of contaminants may give promising results in the future. Despite their minuscule status, nanoscale particles may hold potential to cost effectively address some of the challenges of site remediation (Tina and Zhang, 2003, Rai *et al*., 2018a) [82, 92]. Nanotechnology can prove helpful in providing a way to purify the air and water resources by utilizing nanoparticles as a catalyst and/ or sensing systems (Fulekar *et al*., 2014) [16]. Nano-sensors may be applied in food safety analyses, especially in determining the extent of contamination in food crops (Kuswandi *et al*., 2017) [29]. Yang *et al*. (2006) [87] have found that application of nanostructured materials can be used as adsorbents or catalysts to remove toxic and harmful substances from wastewater and air and finally from soil. In order to understand possible benefits of applying nanotechnology to agriculture, the first step should be to analyze the level of penetration and transport of nanoparticles in plants. It is established that these particles tagged to agrochemicals or to other substances could reduce injury to plant tissues and amount of chemicals released into the environment. Some contact is, however, inescapable, due to the strong interaction of plants with soil growth substrates (Monica and Cremonini, 2009) [39]. In the field of nanotechnology, production of nanomaterials and products containing them are rapidly developing fields, which provides many opportunities for new innovation. For the abatement of pollution, production in the field of nanotechnology is just a beginning. It can be explored to catalyze the important changes in the field of environment. Applications of nanotechnology in water treatment and purification have witnessed significant developments in recent years (Theron *et al*., 2008; Mauter and Elimelech, 2008) [81, 36]. Liu and Zhao (2007) [31] prepared and tested a new class of iron phosphate (vivianite) nanoparticles for in situ immobilization of lead in soils. Batch test results showed that the nanoparticles could effectively reduce the leachability and bioaccessibility of lead from soils. Liu (2011) [32] also reported an effective remediation of a lead-laden soil from a shoot range using synthesized apatite nanoparticles. Rathore *et al*. (2013) [56] have found that the application of carbon nanoparticles resulted into 75–92 % reduction in Ni contamination from soil and about 99 % reduction from water system. Carbon nanoparticle have exceptional adsorption and mechanical properties due to its unique electrical property, highly chemical stability and large specific surface area (Salam, 2013) [60]. Singh *et al*. (2013) [70] have also used zero-valent iron nanoparticles for removing Cr from contaminated soil and reported about 99 % removal of Cr.

Biotechnological tools include genetic engineering in order to improve the performance of plants in effective removal of metals from environment. With the help of this technique, overall functioning of plants can be altered. Addition of new genotype and phenotype by transferring the gene from metal-hyperaccumulating plants and microbes increases the remediation property of plants (James and Strand, 2009) [22]. To clean the environment, cooperation, integration and assimilation of such biotechnological advances are required (Mani and Kumar, 2013) [34]. Aken (2008) [1] has observed that transgenic plants can be safer for phytoremediation purpose. Isolation of quantitative trait loci (QTL) associated with tolerance of Zn metal in *Arabidopsis halleri* can be used for identifying the main genes responsible for adaptation against the metal stress (Nancy *et al*., 2007). When the bacterial merAB operon was transferred to the chloroplast genome of tobacco plant, then the plants showed more resistant toward highly toxic organic mercury (Heaton *et al*., 2005) [19].

4. Conclusion

Accumulation of heavy metal in plant due to uptake from soil system, cause oxidative stress in plant and thus interruption in various metabolic process. Excess accumulation of heavy metals in food crops are responsible for carcinogenesis, mutagenesis and teratogenesis in human. Use of cost effective technique such as natural sorbents (farm yard manure, vermicompost, saw dust, rice husk) can be one of the potential measure, which can be effectively used in place of conventional expensive sorbents. Natural products like farm yard manure (FYM) and vermicompost (VC) are available from waste product and can be potentially used in combating heavy metal pollution in soil by the process of absorption and translocation of heavy metal in soil which is largely governed by organic subtances present in soil. Chelates too form organo-metallic complexes in soil system and can be used for combating heavy metal toxic stress condition in soil. Phytoremediation is one of the emerging technology using selected plants to clean up the contaminated environment. Nanotechnology, beacuse of its unique property of adsorption and high chemical stability is the most recent technological breakthrough in the field of agriculture and remediation of pollutants like heavy metals from soil system. Thus, in present scenerio, where much emphasis is put on sustainability, these technological interventions can be a beneficial approach in combating heavy metal pollution in soil as well as attaining overall goal of sustainability.

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