Chapter 2

The Pollution of Water by Trace Elements Research Trends

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Additional information is available at the end of the chapter

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Abstract

Water pollution has been a growing issue for the last decades. This is mainly because of the boost in human population, and the motivations that lead to technological advances for the welfare of the society. Water pollution originates from different sources such as agricultural, municipal, industrial, and landfills drainage waters. These pollutants, which are either organic, nutrient, or heavy metals pollutants, are very deleterious to the natural ecosystems and eventually harmful to humans. Different procedures have been proposed for handling heavy metals water pollution, which encompass electro-osmosis, ion exchange, electrokinetic, sludge activation, as well as phytoextraction. Water contaminants are also removed using flotation, membrane filtration, aeration, precipitation, coagulation—flocculation, ion exchange, and electrochemical treatment. These procedures are costly and have prompted the use of other techniques, such as phytoremediation. Phytoremediation involves the utilization of plant species to alleviate the impacts of environmental pollution. It could be implemented to eliminate pollutants from various natural ecosystems including water, soil, and air or to develop new vegetation growth on disturbed or barren ground. Different plant species have been used for phytoremediation. This chapter addresses trace elements pollution of natural water resources in details and the abilities of Aquatic plant communities such as Reed plants (*Phragmites australis*) to absorb soluble trace elements from water.

Keywords: water pollution, trace elements, research trends, phytoremediation, *Phragmites australis*

1. Introduction

Water pollution is one of the biggest challenges that humans face in recent years. The control of water and soil pollution has been tackled in many studies conducted worldwide to find ways and means to eradicate this major problem. Different methods for extracting pollutants were developed to be used at the commercial level. With the advancement of technology, extraction techniques are more rapid than before, however radioactive, biological as well as toxic pollutants greatly increased to levels, which render natural water resources toxic especially if the pollutants accumulate beyond certain levels. This chapter addresses trace elements pollution of natural water resources in details and the abilities of Aquatic plant communities such as Reed plants (*Phragmites australis*) to absorb soluble trace elements from water.

The Reed plants are commonly growing in different habitats throughout the world ranging from deserts, coasts, to mountains. The Reed plant poses a great problem when they invade fertile farm lands and causes water leaching. These plants possess potential efficiency for heavy metals uptake via their roots and shoots during their growth. The use of phytoremediation (with Reed plants) as a cheap and clean technology, encouraged numbers of researchers to develop new methods to remove trace elements from the natural ecosystems. Researchers have constructed large wetlands using reed plants to remove pollutants [1, 2]. These research experiments included wastewater, sludge, and sewage as well as industrial waste water, where aquatic plant species beds were used for water purification [3].

Trace toxic elements include Cu, Cd, Pb, Cr, As, and Hg, which are needed for living things within certain levels, and if more concentrations of these metals are taken, they are harmful to living organisms. These elements are generally not toxic in their metallic form, but when they are present in fine powder form, they can toxic if inhaled or ingested. Usually, their compounds with other elements are poisonous to living organisms [4].

Copper, Chromium, Cadmium, and Lead are among the main pollutants of water resources that have densities more than 6 g/cm^3. Cu, Cd, Pb, Cr levels in the soil solutions fluctuate between 1000 ppm and few. However, manganese level in the soil solution ranges between 20 and 10,000 ppm. Some kinds of soils may have higher concentrations of these trace elements. When the concentrations of these trace elements extremely higher levels in the soil environment, the soil is said to be polluted with heavy metals and cannot be used for agricultural crop production. The increase in the concentration of heavy metals in the soil environment could be attributed to human activities, such as the production of energy, agricultural production, and mining [5–7]. All these activities cause the buildup of heavy metals concentrations in the soil solution which eventually, ends up in the tissues of the different plant and animal species as well as human [8], and heavy metals may accumulate to toxic levels in the ecosystem [9].

The application of both chemical and animal fertilizers to crop plants increased the concentration of heavy metals greatly in the soil solution, thus polluting underground water resources. In addition, the accumulation of plant nutrients, such as nitrogen (N) and phosphorus (P), due to the high rates of fertilizer application to crop plants, in surface water resources lead to what is known as Eutrophication. Eutrophication results in an increased growth rate of plant species, e.g., algae. In addition, the extensive use of fertilizers in crop production leads to heavy metals buildup in the different water resources [10]. The high accumulation rate of chemical substances and heavy metals causes a notable threat to both human and animal health [10, 11].

2. Water pollution

Water pollution scale: Water pollution is mainly attributed and distributed by human activities in the agricultural sector as compared to the industrial sector [12]. Research and development in the field of water pollution is focused on the remedial techniques worldwide in the last three decades. Water pollution can happen due to accidental, carelessness, or illegal discharge of polluted wastewater in the natural surface water resources. Such incidents occur more due to the lack official regulations, monitoring.

Procedures and public awareness about the consequences of water pollution [13, 14].

3. Water pollution sources and implications

The main sources of the pollution of water resources are the drainage of wastewater from cropped farms, factories, and municipalities that is defined as **point source pollution**. The amount of this type of water pollution decreases as the distance from the point source is increased and it can easily be monitored and controlled. However, in **diffuse pollution source**, pollutants get in water from diversified sources such as atmosphere, agricultural chemicals, i.e., fertilizers and pesticides, drainage, sewage industrial wastewater, infiltration of ground water. The impacts of pollution from diffuse source could be troublesome. Most methods are developed to treat point source pollution. Water pollution exhausts the concentration oxygen dissolved in water sources and influences both pH and temperature levels that must be stable for aquatic organisms survival in the ecosystem [12]. Oxygen is considered as a limiting factor for the growth and development of fish, which need high amounts of oxygen for their metabolic activities; however, the increase in temperatures levels will reduce the oxygen solubility in water and thus reducing its concentration to meet fish needs [15, 16].

3.1. Organic pollutants

This is considered one of the ancient water pollution kinds when organic matter is discharged into water sources. The main source of organic pollutants is farm's drainage water that contains animal waste and agricultural chemicals (pesticides, herbicides, and fertilizers), domestic wastewater, and industrial water. Suspended organic matter constitutes the main percentage of organic wastes and it can be monitored as the levels of oxygen concentration [14, 17]. The main components of an organic waste typical composition are lignin, cellulose, lipids, protein, amino acids, and ash [18]. The chemical reactions that happen to these materials, while they are present in water resources could lead to the depletion of water oxygen content that may finally have a negative impact on the ecosystem. The strength of wastewater that causes the organic pollution is usually measured by its biological oxygen demand (BOD), which is expressed as mg/liter.

3.2. Nutrient pollutants

There are several factors that are detrimental to plant growth, these factors include the availability of macro and micro nutrients, e.g., nitrates, phosphates, etc. [12, 19], when the discharged organic pollutants are decomposed, they make available phosphates, nitrates and other nutrients for plant growth. However, the high growth rate of plant species may have negative effects on the aquatic environment. The negative impacts include [12]:

1. The physical alterations in the habitat may cause faunal changes in the populations of filamentous and macrophytes algae.
2. The dissolved oxygen concentrations may be depressed due to the respiration of the densely growing aquatic plant species.
3. Algal species bloom may cause several problems regarding water qualities, and the water might tend to be poisonous to aquatic animal species, including fish.
4. Plant species biomass decay may create huge amounts of organic sediments that may adversely affect the aquatic ecosystem.

3.3. Heavy metal pollutants

The chemical pollutants may include both organic and inorganic materials, although many inorganic substances, such as metals, are considered important for the well-being and survival of living organisms in any environment. High or low metal concentrations can have negative impacts on the environment. There are two major groups of toxic metals: (a) Mercury (Hg), Lead (Pb), Cadmium (Cd), and Arsenic (As) which are non-essential and (b) Zinc (Zn), Chromium (Cr), Copper (Cu), and Nickel (Ni) which are essential to plant and animal species growth and development. These trace elements may give rise to soil, water, and air pollution, which has been studied by many scientists [13].

Pollution resulting from human activities produces wastes rich in metals content which rises their concentrations in the natural ecosystem, especially water resources to toxic levels. The major human activities that lead to water pollution include industrial wastewater, agricultural drainage water, sewage water, and oil pollution. Water pollution is considered a major problem that causes many diseases all over the world. About 14,000 individuals lose their life daily due to heavy metal water pollution [20, 21].

The developments in the technological and industrial sectors depend on the use of the minerals natural source and the aquatic ecosystems are considered as the final recipients of their toxic, solid as well as drainage waste water. The national water quality report of United States of America, for example, indicates that 45% of tested stream miles, 47% of tested lake acres, and 32% of bay and estuarine square miles are described as polluted [22].

The protection of human health and aquatic ecosystem well-being is a fundamental concern all over the world, and it has been deem necessary that ways for the management of aquatic resources should be considered within the dynamics of the ecosystem conditions and their exploitation for human needs continues to be sustainable [23].

The exposure of individuals to toxic elements, such as Arsenic, Cadmium, Chromium, Mercury, and lead, can result in serious health hazards [24]. The sources of these toxic elements include mainly chemical industries drainage wastes, medical waste, excessive use of fertilizer and their production, oil refineries, and pharmaceutical industries. These waste waters carry sulfide, pyrite, pyrhotite converting into sulfate into ground water, rivers, and lakes [25] (**Table 1**).

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Element	Max. admissible conc. (mg/dm^3)	Max. permissible conc. (mg/dm^3)
Cd	0.005	0.01
Cr	0.05	0.10
Cu	0.05	15.00
Pb	0.05	0.10
Zn	5.0	15.00
Source: [33].		

Table 1. The WHO admissible and permissible levels of trace elements in fresh water.

Many different studies in the fields of heavy metals pollution [26–32] have covered topics such as:

1. Constrains of soil and water environmental standards.
2. Environmental conditions and pollutant sources.
3. Pollutant concentration levels.
4. Chemistry of toxic water pollutants.
5. Solubility, adsorption, dispersion, volatility, and movement of chemical pollutants.
6. Hydrogeology of polluted sites.
7. Monitoring of the quality of groundwater.
8. Chemistry and mechanics of soil pollutants.

The exposure for a long period of time to different concentrations of heavy metals may lead to grave health and environmental consequences and some of these metals are deleterious, such as As, Pb, and Hg. The trouble regarding these metals is the fact that they do not degrade or accumulate, but can be transmitted from one environmental site to another, these facts for their inclusion, handling, sweep, and drainage Ho and El-Khaiary, Long et al., Nriagu [34–36].

4. Water pollution treatment method

The researchers, government authorities, and businessmen have endeavored to tackle heavy metals pollution of water, air, soil, and its impacts on human bodies. Many technologies and regulations have been formulated to deal with the monitoring and determination of heavy metals pollution and convenient arrangement are taken [37, 38].

Different laboratory and field mechanisms have been proposed for handling heavy metals pollution [39], which included electro-osmosis [40], ion exchange [41], electro-kinetic [42], sludge activation [43] as well as phytoextraction [44–47]. Water contaminants are classically removed using different procedures such as flotation, membrane filtration, aeration, precipitation, coagulation-flocculation, ion exchange, and electrochemical treatment [34, 48]. These classical procedures are thoroughly discussed in the literature [49, 50]. However, these procedures are costly and have prompted the use of new techniques, such as phytoremediation. The different new techniques that are used for the control of heavy metal pollution include immobilization, soil flushing, electro-kinetics, phytoremediation, etc. [51].

4.1. Phytoremediation

Phytoremediation is the process in which plants are used to get rid of environmental pollutants. It takes into account all physical, chemical, or biological approaches that use plant species for decontamination of polluted sites. Two basic principles applied in this technique are phytoextraction (harvesting) and phytostabilization (root fixing) [13, 52–55]. Aquatic plant species are capable for the extraction and accumulation of heavy metallic pollutants without severely affecting their growth in the polluted site [56, 57], that nominates them for the treatment of heavy metals pollution [58]. Using phytoremediation to extract heavy metals from both natural water as well as soil resources is a feasible economic and non-ambiguous action [59]. The aquatic plant species *Phragmites australis* is a perennial grass that naturally grows in wet habitats throughout the world. This plant can tolerate environmental stresses such as heavy metal pollution [60]. *Phragmites australis* plants are widely used in the construction of artificial wet sites for the treatment of industrial drainage water rich in its heavy metal contents [56].

4.2. Rhizofiltration

Rhizofiltration is one of the phytoremediation mechanisms that employs the roots of plant species in the uptake, accumulation, and sedimentation of heavy metals from drainage water and contaminated soils. Rhizofiltration utilizes overland plant species because these plants are characterized by longer and fibrous root systems that are covered with root hairs, which increase their absorptive, surface areas [46, 61]. In this phenomenon, metal uptake does not encompass any biological procedures [13, 62]. *Eichhornia crassipes* plants can accumulate Cd and Pb at a concentration of more than 6000 ppm in plant tissues [63, 64]. *Azolla filiculoides* Lam water Fern can uptake Cd, Cu, Ni, and Zn from the soil solution at levels of 10,000, 9000, 9000, and 6500 ppm, respectively [65, 66]. *Nelumbo nucifera* Gaertn and *Nymphaea alba* L. plants can accumulate Cr up to 3000 mg Cr kg [67]. Severe toxic effects on health are observed at low concentrations of 0.5 mg/L for Cr (VI). Cr (VI) is considered as lethal for human being at a dose higher than 3 g same as an example of Cr, other metals Cu, Cd, and Pb also cause high degree of pollution based on their toxicity and their ability to generate different compounds in water. Thus, it can be noted from this discussion that heavy metal pollution of soil and water can be treated using plant species. The drastic permanent solution can be obtained if we choose the right plant species to be used after knowing the actual causes of water and soil pollution.

Government personnel, scientists, and the public are concerned about the ever growing ecological threats that include global warming, the diminishing natural resources that promoted intensive research for the development of new techniques for removing heavy metals from the polluted sites, such as using plant species, improving existing and new decontamination procedures

[13, 68, 69]. The problem is also amplified in advanced as well as developing countries, as a result of the ever increasing industrialization and auricular development releasing high amount of toxic materials if their drainage water into the existing natural ecosystems [56, 68, 70, 71].

All these consequences have promoted the use of phytoremediation for the removal of toxic pollutants, because aquatic plants grow and flourish naturally in drainage canals [2]. Phytoremediation, using aquatic plants such as Reed plants, provides a chance for its use as a feasible non-destructive technology to eliminate pollutants from soils or water ecosystems. This was assured by the work of many scientists who analyzed aquatic plant tissues for their mineral contents [55, 72, 73].

5. Reed plants characteristics

Reed (*Phragmites australis* (PA)) plant is a perennial aquatic plant species that has given wide attentiveness for treating heavy metal polluted soils and water sites due to the fact that it can tolerate the adverse effects of high levels of toxic metals, without affecting its growth and high yield rates, PA can naturally grow well in natural or artificial sites polluted with Zn, Ni, Pb, As, and Cd [3, 74]. It is recorded growing naturally in low-level coastal plains or river-flooded areas in North America, Europe, Middle East, Africa, and Australia.

The reed plants can grow to a stem length of more than 350 cm and is characterized by its efficiency to move O_2 from its shoot zone to its root system. The root system can develop and extend even in water-logged environments [65, 66]. Kilkuth in Germany used Reed beds for drainage water treatment in 1970s and in England in 1985 [75].

6. Heavy metal pollutant control methods

Lower concentrations of Copper, Selenium, and Zinc are essential for human body’s metabolism, but at higher concentration, these metals (Fergusson [17]) as well as Mercury, Cadmium, and Lead are toxic and can eventually cause a number of diseases that lead to muscular, neurological, and physical degenerative impacts. In recent years, different procedures were developed to eliminate metal pollutants from drainage and drinking water [12]. These procedures are discussed as follows.

6.1. Chemical precipitation

It is considered as one of the widespread procedures for the removal of metal ions from water solutions [76]. The methodology involves the production of metallic hydroxides, e.g.

$$M^{n+} + n\,(OH-) \rightarrow M\,(OH)_n. \quad (1)$$

where M (OH) is the metal insoluble hydroxide, Mn^+ is the dissolved metal ions, and OH^- is the precipitant.

The main hindrances of this procedure are the high amounts of chemicals used, and excessive wastes that are produced which need to be eventually treated. In addition, cumbersome metal deposition, fiddling sediment of hydroxides, assemblage of metal depositions, and long-term effects of the disposal of wastewater also need to be taken care of [77, 78].

6.2. Coagulation-flocculation

Coagulation and flocculation happen in successive operations in order to upset the stability of the unsettled particles, to permit particle impact and to regulate the growth of aggregates. Both operations must be achieved to accomplish the elimination of pollutants [79]. Coagulation, fore mostly, takes place to upset the stability of the particles leading to their precipitation. Flocculation increases the size of the particles through the aggregation of unsettled particles. This is mainly accomplished by pH modification and addition of ferric or aluminum compounds to control the dissonance within the colloidal particles. The use of lime, as coagulating agent, improves the settlement of the sludge, reduces watering, and makes it capable for controlling bacterial activities. The main drawback of the use of lime is the high costs [78].

6.3. Flotation

This methodology is effective for liquids as it uses bleb connection to split up solids. There are five kinds of flotation, i.e., biological-, electro-, vacuum-air-, dissolved-air-, and dispersed-air flotation. The most widely used one for metal removal from drainage water is dissolved-air flotation [79].

6.4. Aeration

Aeration is needed when the water has oxygen shortage condition due to municipal, agricultural, and industrial drainage water discharge. Aeration is conducted by introducing air at the bottom of the water reservoir or by surface stirring generating a basal device that allow air and water mixing which would help in releasing and removing of harmful gasses, e.g., hydrogen sulfide, carbon dioxide, and methane [78]. It can be utilized to handle both drainage and drinking waters. It can be classified into surface, sub-surface, and natural aeration [79].

6.5. Membrane filtration

This technique is beneficial because no chemicals were used, and has a comparatively minimal energy use and it can easy be conducted in gradual stages. This process can be used to remove dissolved pollutants, e.g., organic compounds, suspended solids, and heavy metals. There are different sorts of filtration mechanisms that can be used, based on the targeted particle size that is required to be removed. These mechanisms include reverse osmosis (RO), ultrafiltration (UF), and nanofiltration (NF). Ultrafiltration uses permeable membranes with pores ranging between 5 and 20 nm depending on the material to be extracted. Nanofiltration technique depends on the steric effect as well as the electrical effect. It utilizes the electrical charge differences between the membranes' anions and the pollutants' cations that results in repulsive forces to separate these metallic pollutants. In reverse osmosis, the exerted pressure forces keep the trace elements and clean water can be collected from the second direction of the membrane. Reverse osmosis is more efficient as compared to ultrafiltration and nanofiltration mechanisms, since it extracts 97% of the targeted heavy metal in the 20–200 mg/L range [13, 78].

6.6. Ion exchange

The exchange of ions of the same charge between an insoluble solid and a solution in contact with it used in water-softening and other purification and separation processes. Thus, metals can be extracted from solution with the help of suitable reagents [13]. This procedure is effective when pH of the solution (polluted water source) ranges from 2 to 6 and demands the removal of the suspended solids by other methods prior to the implementation of the ion exchange method [79].

6.7. Electrochemical treatment

This procedure performs metal extraction using the combination of membrane and ion exchange mechanisms. The main methodology is accomplished by passing polluted water through an ion exchange membrane. This membrane consists of thin plastic materials that have either cationic or anionic electric charge. This methodology is efficient, although it is expensive as far as chemicals, sludge handling costs, and its high-energy use [13].

6.8. Microbial biosorption

The utilization of non-living microbial tissues for retaining heavy metals, which is not a metabolic activity, is defined as biosorption [80]. The microbial cells are good biosorbents because they have a high surface area, and thus have high number of biosorption sites. Industrial activities, such as electroplating and mining, produce high amounts of biomass that could be used in the removal of heavy metal pollutants [25]. Biomass can be also been grown using fermentation techniques and inexpensive growth media. Dead cell biomass can be more beneficial as compared to live cell biomass, as systems utilizing living cells can be affected by metal ion concentrations, temperature, pH, and constant requirement of nutrient supply for living cells [13, 81]. The industrial waste when fermented can be processed into biomass. Microbial cells in the biomass can be removed by many methods such as heat treatment, autoclaving, and vacuum drying, using acids, alkalis, detergents, organic compounds, and mechanical disruption.

The effective amount of absorbing material to be used can be estimated by comparing its strength to remove the sorbent material from polluted water with other substances reported in other studies. The amount is defined in terms of the amount of heavy metal extracted (milligrams) per amount of sorbent used (gram). The biosorption methodology is affected by pH, temperature as well as the ion concentration in the solution [80].

6.9. Phytoremediation

Phytoremediation is a technique that uses plant species and associated-soil micro-organisms to extract metals present in the ecosystem, i.e., air, soil, and water [82, 83]. Phytoremediation is now utilized for treating pollutants, e.g., heavy metals, fertilizers, pesticides, chlorinated solvents, petroleum hydrocarbons, explosives, etc. All other traditional methods for the removal of heavy metal pollutants from the natural ecosystems are costly and use large quantities of chemicals and create waste treatment problems, even if these procedures are advantageous for their rapid extraction of pollutants in small sites [17].

Phytoremediation surpassed the traditional procedures because it helped in maintenance of biological activity, site restoration, and partial decontamination as well as it is unobtrusive, has a possibility of bio-recovery of metals and not costly [47, 84]. Due to these merits, phytoremediation is enumerated as a "green," sustainable pollution remedy procedure. Phytoremediation has been classified into five divisions:

i. Phytoextraction: plants uptake metals and accumulate them in the usable tissues [85];

ii. Phytodegradation: plant species and associated micro-organisms break down organic pollutants [86, 87];

iii. Rhizofiltration: the plant's root system absorbs metals from polluted water sources [46, 51];

iv. Phytostabilisation: plant species reduce pollutants bioavailability in the natural ecosystems by fixation or by prohibition of their migration [88] and,

v. Phytovolatilization: volatilization of pollutants into the atmosphere through plants [86, 89]. The next section explains a detailed review of this emerging green technology.

vi. Phytovolatilization: the evaporation of pollutants into the air via plants [86, 89].

The advances in the fields of research and technology have promoted the growth of different industries resulting in matchless unrests in the ecological cycles [78]. The recent admission of toxic chemicals and resettlement of natural substances into different ecosystems (soils, water, and air) have given rise to major demands of self-purifying capacity of the natural ecosystems [90, 91].

The present off-site procedures for treating polluted water resources include extracting and treating of pollutants using adsorption capacity of activated carbon, micro-organism or air denudation; while on-site procedures for treating polluted water resources include stimulation of aquifers aerobic and anaerobic micro-organisms activities. All predominant procedures are expensive and require high technical human resources to execute. Thus, stakeholders are looking forward for the development of cheaper and speedy techniques for treating highly contaminated water resources, wetlands, and soils [13].

It is claimed that about 80% of the contaminated soil water is found within the top 20 m of the soil depth. This indicates that the removal of water pollutants can be performed using the cheap phytoremediation technology [92]. Many experimental studies have been conducted on the use of plant technologies in treating contaminated natural resources [93–96]. The various phytoremediation methods encompass: the adjustment of the physical and chemical characteristics, liberation of the root exudates, amend aeration and allow more of the oxygen to reach the root zone, oppose and reduce the transport of chemicals, affect the shared metabolic activities of plant and micro-organisms' enzymes, and deduce the vertical and horizontal movement of contaminants [97]. When the water pollutants, i.e., heavy metals, are found in low concentrations, phytoremediation may prove to be the most feasible technique for their treatment due to its cheaper costs and its efficiency [98].

The main phytoremediation procedures can be classified as on-site, in a living organism and off-site types. On-site phytoremediation is the modest and cheaper of all three classes and the plants are growing in direct contact with pollutants.

There are numerous technicalities by which plant species can rectify water and soil pollution. During phytoremediation, the merits of the technique can be influenced by physical and chemical pollutants traits (molecular weight, vapor pressure as well as their solubility in water), environmental traits (organic matter in the water solution, pH as well as temperature), and plant traits (root system characteristics and enzymes) [90].

7. Use of plants for the treatment of pollutants

Many plant species have capabilities to uptake and accumulate high levels of metallic organic compounds without any toxic impacts, such as reed plants (*Phragmites australis*), Indian mustard (*Brassica juncea* L.), willow (*Salix* species), poplar tree (*Populus deltoides*), Indian grass (*Sorghastrum nutans*), sunflower (*Helianthus annuus* L.), water hyacinth (*Eichhornia crassipes*), channel grass (*Vallisneria spiralis*), alfalfa (*Medicago sativa*), brassica (*Brassica napus*), kenaf (*Hibiscus cannabinus* L.), tall fescue (*Festuca arundinacea* Schreb), bermudagrass (*Cynodon dactylon*), and barley (*Hordeum vulgare* L.) [13, 99].

These plant species have attained heavy metal tolerance characteristics that modified them to survive in highly heavy metal polluted ecosystems [13, 99], and they show high strength to accumulate heavily metallic ions, such as nickel, zinc, copper, chromium, and even radionuclides. The threshold for hyper-accumulation of heavy metals is known as the accumulation in plant tissues of concentrations greater than 0.1% on dry weight basis and not less than 0.01% for cadmium. Many types of plant species could be utilized in phytoremediation [61]. These plant species have specific characteristics that assist in their normal growth in polluted sites and at the same time uptake and accumulate heavy metals in their roots and shoots [100, 101]. Reed (PA) plants are plant species that are widely dispersed and are found in wide range of habitats worldwide [102]. PA plants are aquatic perennial grass [103]. A number of studies have been conducted on PA plants growth and development [104], mineral content [105], response to heavy metals [49, 104, 106–108], response to salt stress, [108, 109] as well as the different reed plant subspecies phenotypic, genotypic, evasive characteristics [49, 96, 109]. The results on the available research studies indicated that reed plant species significantly differ in their response to salt stress [102, 109, 110], this could be due to genotypic differences [103, 111]. This is expedited by limited intake and conveyance to the shoots of sodium, sulfur, and to some extent Chlorine, the capability of maintaining a comparatively high photosynthetic rate, the capability of promoting water use efficiency, and proline production of osmotic adjustment. NaCl and Na_2SO_4 influence the water and gas operations during photosynthesis. NaCl is more poisonous to plants than Na_2SO_4 [109].

The reed plants can tolerate high-environmental stresses due to their ecological, physiological as well as morphological characteristics and will develop normally in heavy metal (Zn, Cd, and Pb) polluted ecosystems [112]. These plants possess high phytoremediation as well as detoxification traits and have been excessively utilized in the construction of artificial wetlands for the treatment of heavy metal pollution of industrial drainage water [113]. With the recent improvements in the application of scientific knowledge of phytoremediation for practical purposes, especially in pollution eradication and the search for greener alternatives for pollution enucleation, the interest has been directed toward reed plants reactions to heavy metal environmental stresses [114, 115]. However, how reed plant cells become tolerant to toxic heavy metal levels and why they are hyper-accumulator of these metals is unknown [114].

Tylova et al. [104] compared *Phragmites australis* and *Glyceria maxima* plants, which are plants adapted to growing in saline conditions, as in a salt marsh. They found that the nitrogen accumulation of the two plant species in their underground tissues did not worth considering. The annual production of the two plant species was the same, but they differed in the allocation of biomass between their rhizomes and roots. Reed plants assigned more dry weight to rhizomes as compared to Glyceria. This is demonstrated in **Figure 1**.

Reed plants were found to be more tolerant to N, P, K, ammonium compounds as well as to salt stresses as compared to Glyceria plant [108]. This was reflected by the growth of reed roots to greater soil depth, where the accumulation of NH_4^+ ions was evident, which improved reed plant tolerance to mechanical damage, mowing, and grazing [108]. Unamuno et al. [107] investigated reed plants' copper adsorption and reported that initial adsorption of Cu was high in the plants vegetative litter; but after 50 min, it decreased drastically. If the reed plants shoots were not harvested from time to time, then the plants could accumulate high amounts of the toxic metals and when they get dry, the vegetative parts would decompose and raise the waste water toxicity [116, 117]. During the movement of the cations from the soil solution to the root systems of the plants, only a small percent of free hydrated ions occur and their movement into the cell require metabolic reactions between the two media [118, 119]. The metal intake capability can be improved by root activities as they liberate solubilizing enzymes that stimulate this method in the rhizosphere [120]. Roots also liberate organic acids, flavones, nucleotides, amino acids as well as sugars [13]. This method is also affected by constancy of different metals chelates under different pH values because factors released by root cells are normally pH specific in the chelating process [121]. The intake of cations by the root system cells depends also on their concentration in the soil solution [12, 17, 122].

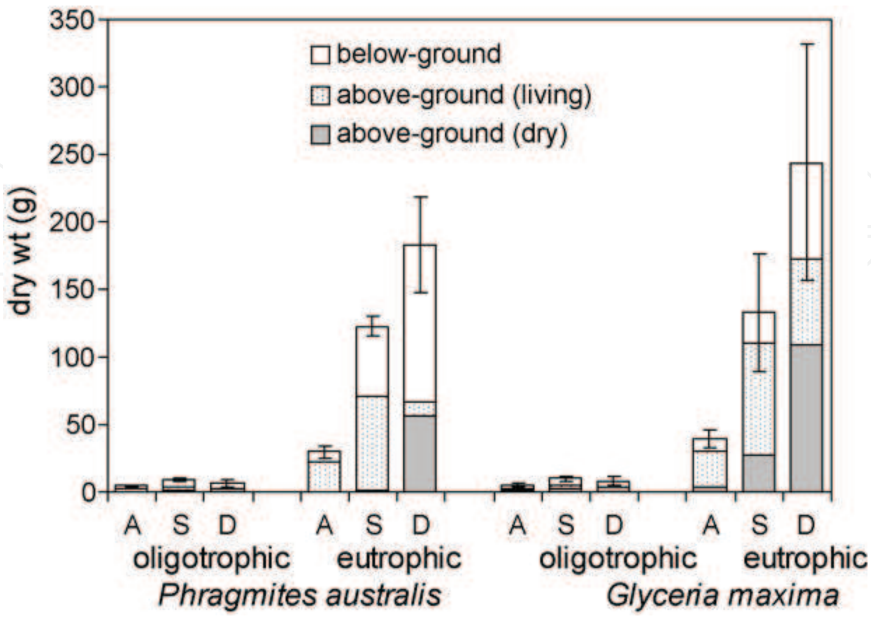

Figure 1. Below ground tissues development in reed and Glyceria plants source: Tylova et al. [104].

Vymazal et al. [49] claimed that heavy metals levels were reduced in the order of roots > rhizomes ≥ leaves > stems of the reed plants and that the heavy metal (Cd, Cr, Cu, Ni, Pb, and Zn) levels in the shoots and roots plant tissues were the same as those reported for plants growing in natural ecosystems. However, these levels were much less than for plants that were irrigated with mines, smelters, or highway drainage waters. The mean leaf to stem ratio and root to leaf ratio of metal content was found to reach 1.5. The metal uptake level can greatly be increased by increasing the nutrient availability to reed plants. These plants usually have high growth rates during the growing season even when planted from the seeds or rhizomes. This indicates that the handling of reed plant seedlings can be more discreet without paying any attention to the present situation of eutrophication [106].

Bragato et al. [123] determined the uptake of Zn, Cu, Cr, and Ni in a constructed wetland and reported that the distance from the inlet had no impact on the shoot dry weight or N, P, K, Na, Zn, Cu, Cr, and Ni contents in the aerial parts of the plants. With the exception of Na, reed plants adsorbed more of these elements than *Bolboschoenus maritimus* Reed plants heavy metal accumulation was found to increase at the end of the season. Heavy metal level in the arriving water as well as in the soil was not correlated to the amount of heavy metals of the growing plants.

8. Heavy metal accumulation in plant species

A metal assemblage depends on the ability of plant cells to uptake minerals and the number of binding sites present in the intracellular spaces. Drainage water or water contaminated with micro- and macro-organism has complications regarding specific cells and tissues differences, within cells transport level, consanguinity of chelating particles, as well as transport efficacy that can influence the rate of mineral accumulation [118], as well as operations like movement and uptake of ions from the soil solution, assortment and retention inside the root system, effectiveness of xylem for loading and transmitting of ions, allocation of ions in the different ion sinks in the shoot, confinement and pilling of the various ions in leaf cell [49].

By piling up of heavy metals, strange substances in ecosystem and radioactive nuclides via phytoremediation traits of plant species, the treatment of polluted water and soil resources will be feasible. When heavy metals have been accumulated in plant tissues, they will be turn into save metabolites. In addition, the heavy metals can be transported to plant shoots that could be harvested. The harvested material could be dried and then ashed or composted. During these processes, the amount of waste produced would be minimal when compared with other mechanisms of waste disposal [124]. Plant species that accumulate high concentrations of various cations are of high biogeochemical and environmental research importance.

9. The commercial use of reed plants for phytoremediation

Phytoremediation is a technique for treating polluted sites and it does not cause any damage and it is cheap, however it has not been utilized fully at commercial basis. Many USA

Site	Plant species	Pollutants	Applied Procedures
Trenton, NJ	*Brassica juncea*	Lead	Phytoextraction
Anderson, SC	*Populus deltoids* × *P. balsemifera* (hybrid polar) grasses	Several heavy metals	Phytostabilization
Beaverton, OR Landfield reclamation [20]	*Populus* spp. (cottonwood)	Unspecified	Vegetative cover/water pollution prevention
Ketowice, Poland	*Brassica jimcoa*	Cadmium and lead	Phytoextraction
Switzerland (landfield)	*Salix viminalis*	Cadmium, copper, and zinc	Phytoextraction
United Kingdom [43]	*Salix* spp.	Nickel, cadmium, copper, and zinc	Phytoextraction Phytostabilization
Hlemyzdi, Czech Republic [43]	*H. annuus*, *C. sativa*, *Z. mays*, and *C. hallery*	Zinc	
Dumach, Switzerland [43]	Improved *Nocotiana* spp. Plants (tobacco)	Cadmium, copper, and zinc	
Lommel, Belgium [43]	Grasses	Cadmium, lead, copper, and zinc	Phytostabilization
Balen, Belgium [43]	*Brassica napus*	Cadmium, lead, and zinc	Phytoextraction

Source: Gardea-Torresdey et al. [124], p. 1807.

Table 2. Commercial application of phytoremediation in USA and Europe.

and European pilot studies indicated that phytoremediation could be performed on large-scale basis. Most of the plant species that are utilized in phytoremediation are trees or herbaceous plants (**Table 2**). Most of these plants have been used in restoring heavy metal polluted sites. The USA market for phytoremediation may exceed 100 million dollars [51, 125]. Phytoremediation, as a technique, is advancing; but according to Glass [125], it would be accepted through social processes and information dissemination about its potential use in removal of specific contaminants. Gardea-Torresdey et al. [124] claimed that phytoremediation could constitute the main technique for handling of toxic wastes in polluted sites in the near future.

10. Conclusion

This chapter provided review of theoretical and practical views regarding heavy metal pollution of soil and water resources, methods to treat heavy metal pollution, phytoremediation concepts, and uses of various plant species in phytoremediation. However, it is not known that metals can be easily be extracted by the different plants and the capabilities of various plants as hyper-accumulator to which heavy metals.

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