DIFFERENT PERSPECTIVES IN MEDICINAL AND AROMATIC PLANTS

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CHAPTER 16

BIOREMEDIATION OF HEAVY METAL CONTAMINATED SITES BY MEDICINAL AND AROMATIC PLANTS: PHYTOREMEDIATION BEHAVIOR

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INTRODUCTION

Rapid urbanization and industrialization have brought environmental pollution. Pollution is even more significant in areas close to industrial areas. Among various organic and inorganic pollutants, heavy metal pollution poses a great threat to the current environment. Because heavy metals tend to stay in the environment for a long time. It takes a long time for them to disappear from nature as a result of chemical and microbial degradation. This feature increases the accumulation and this situation poses a great risk in terms of environment and animal health. Metal concentration above a certain threshold limit will have a toxic effect, thus reducing the quality of soil as well as agricultural products. Therefore, this problem should be handled in the best way and a sustainable environmentally friendly way for treatment should be followed.

It is a worldwide popular and accepted method used for cleaning especially heavy metal-contaminated areas with medicinal and aromatic plants due to its sustainability, non-toxicity, not being included in the food chain because they are not preferred as food due to their essential odor, aesthetic, and natural appearance, environmentally friendly and applicable, accepted by the local people as an aesthetic and safe strategy, and being a low cost and natural method.

Scientists dealing with medicinal and aromatic plants have shown interest in using these plants for phytoremediation purposes in polluted areas. For this reason, studies on this subject have been going on for a long time. In reality, it is used in the perfumery, fragrance, aromatherapy, etc. Such plants, which are of extreme economic importance in areas, are also an excellent choice for the remediation of heavy metal-contaminated areas. In this chapter, this subject will be examined in detail, and examples of work in this field will be given.

1. HEAVY METAL POLLUTION

Soil and water structures are under the influence of toxic heavy metals as a result of rapid industrialization, urbanization, agricultural use, and human activities. Toxic heavy metals such as cadmium (Cd), nickel (Ni), mercury (Hg), selenium (Se), chromium (Cr), lead (Pb), uranium (U), silver (Ag), copper (Cu), strontium (Sr), zinc (Zn), arsenic (As) are continuously left into the environment due to different anthropogenic activities (Figure 1). Industrial wastewater containing heavy metals is generally released into the environment. These wastewaters can cause serious damage to the environment and human health due to their heavy metal content. Because these metals do not undergo chemical and/or microbial degradation. Heavy metals cannot be chemically destroyed like organic pollutants (Keklikcioğlu Çakmak and Topal Canbaz, 2020). These characteristics allow them to accumulate and last longer in the environment. As a result, they pose a serious risk to both the environment and human health (Topal Canbaz et al., 2022). As a result of accumulation in the bodies of living organisms, they can cause teratogenic, mutagenic, and endocrine-disrupting effects (Pandey et al., 2019). The toxicity value of heavy metals may drop or it may take on a less complex structure as a result of the oxidation stage. But they continue to stay in the environment (Mishra and Chandra, 2022). Industrial sources of heavy metals are seen in Table 1.

Figure 1: Anthropogenic Sources (Alengebawy et al., 2021)

Table 1: Heavy Metals Released from Industrial Sources (Mishra and Chandra, 2022)

Heavy metal	Industrial sources
Cd	paint sludge, zinc smelting, waste batteries, fuel and incinerators
Ni	smelting operations, thermal power plants, battery industry
Cu	electroplating, mining, smelting operations,
As	geogenic/natural processes, fuel burning, smelting operations, thermal power plants
Hg	hospital waste, thermal power plants, chloral-alkali plants, fluorescent lamps, electrical appliances
Cr	leather tanning, mining, chromium salts manufacturing, industrial coolants
Pb	smelting, lead-acid batteries, bangle industry, paints, e-waste, ceramics

Today, one of the serious problems for the environment and agriculture is heavy metal pollution. As heavy metals accumulate in the environment, they both have a negative effect on production efficiency and accumulate in humans and animals through the food chain (Pirzadah et al., 2019). Therefore, it is necessary to use some traditional technologies such as isolation and immobilization, mechanical separation, pyrometallurgical, electrokinetic, biochemical, and, soil washing (chemical infiltration), etc. to reduce heavy metal pollution (Rahimi et al., 2022). But, conventional approaches to remediation of heavy metal-contaminated soils are time-consuming, require huge capital costs, and even currently available technologies are not fully successful. Therefore, renewable biological approaches come into prominence. One of these approaches is phytoremediation technology (Arthur et al., 2005).

This book chapter shows the advantages of using aromatic and medicinal plants (AMPs) and the possibilities of use in cleaning contaminated areas as they are high-value economic products. AMPs grown in contaminated soils with heavy metals are safe crops to use as they are not dramatically polluted by heavy metals.

2. PHYTOREMEDIATION

Phytoremediation is the process known as a green technology, in which plants are used to remove pollutants or toxic substances from contaminated environments such as water or soil. Other traditional methods are both very expensive and not very suitable for recovering other toxic substances and heavy metals from contaminated soil or water. Contrary to traditional methods, the main purpose of phytoremediation is the conversion of metals into less toxic or harmless forms without any financial loss or transition to the food chain. In addition, phytoremediation is a more practical and long-term option that improves soil quality with time compared to traditional methods (Mishra and Chandra, 2022). Therefore, the green approach of photo technology to remove toxic metals from polluted areas is seen as a cost-effective, efficient, practical, environmentally friendly, safe, in-situ, viable, publicly acceptable, sustainable, and promising alternative to maintaining soil health (Dar et al., 2020).

3. PHYTOREMEDIATION OF HEAVY METAL CONTAMINATED AREAS

Most plant species can grow in heavy metal-contaminated environments. With the help of these plants, pollutants can be destroyed or reduced through various natural, biophysical, and biochemical processes such as hyperaccumulation or transformation, adsorption, translocation, transport, and mineralization These plants must have special adaptations to survive in such regions (Gupta et al., 2013).

Between 1995 and 2009, a search on Scopus (www.scopus.com) clearly demonstrates how little attention is paid to aromatic plants for phytoremediation (Gupta et al., 2013). Due to the possibility that they could re-enter the human or animal body through the food chain, using edible plants for phytoremediation is neither rational nor practical. The use of aromatic and medicinal plants in the phytoremediation of metal-contaminated soils has been included since this scenario was established (in the last ten years), and the amount of study in this area has been growing daily.

Consumption of edible plants by animals and humans makes them inappropriate for heavy metal phytoremediation. Heavy metals that will accumulate in the tissues of these plants will be transported to the body of humans or animals through the food chain and will lead to unfavorable impacts on health. In other words, the living will be adversely affected by this metal pollution, even if we don't want it at all. Therefore, the use of non-edible plants (eg aromatic and medicinal plants, AMPs) for phytoremediation purposes should be encouraged (Gupta et al., 2013). Growing such plants (AMPs) in metal-contaminated areas will prevent heavy metals from entering the food chain (Figure 2) (Khajanchi et al. 2013; Lone and Gaffar, 2021). Because of the nice smell these plants emit, animals do not harm them as they do not prefer them as food. In this way, it is possible to grow them on a large scale (Dar et al., 2020). The production of essential oils does not contain any toxic metals and therefore prevents their entry into the food chain (Khajanchi et al. 2013). This method is an aesthetic technique that is both applicable and environmentally friendly.

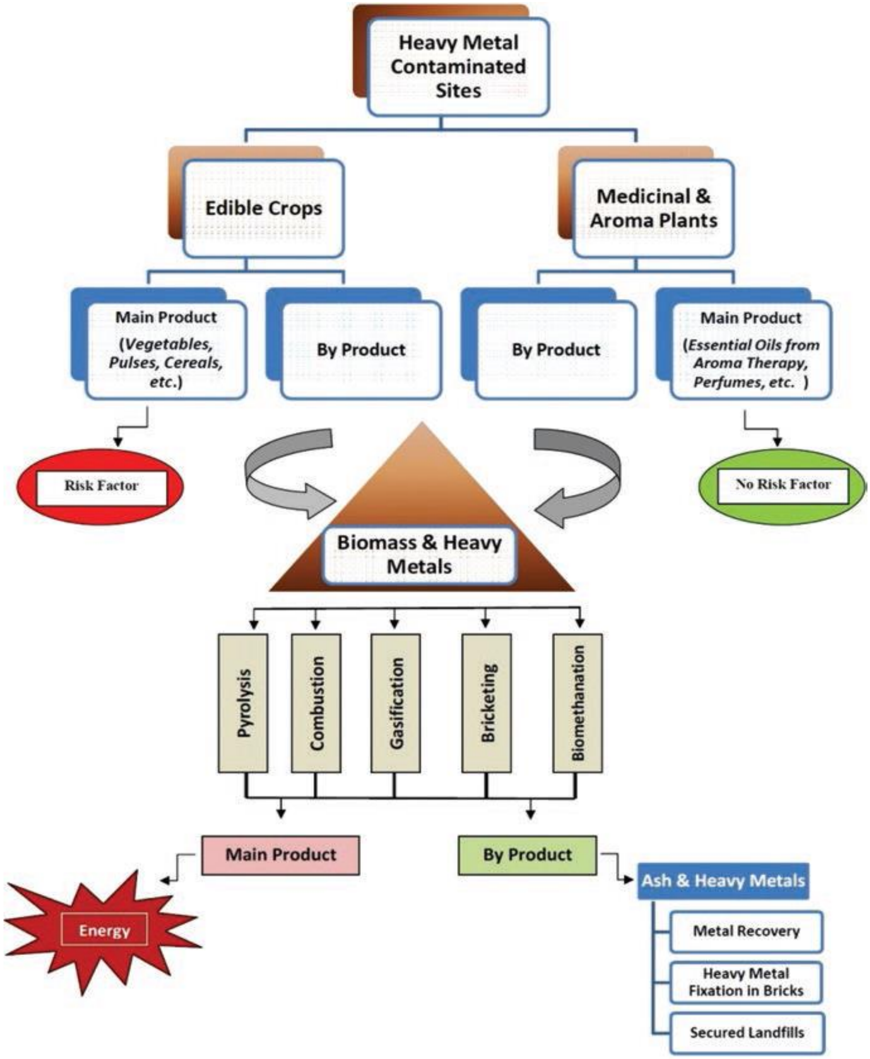

Figure 2: Diagram Showing Benefits of Phytoremediation by Non-Edible Plants Versus Edible Crops (Pirzadah et., 2019; Lone and Gaffar, 2021)

Heavy metal-contaminated soil can be treated using both edible and non-edible crops. Although the phytoremediation capacity of aromatic and medicinal plants may not be very great and they may not be accumulators, these plants can still be used in phytoremediation. As seen in Figure 3, there are many advantages of using AMPs for phytoremediation. AMP resources are quite plentiful and can be used on a large scale (Pirzadah et al., 2019).

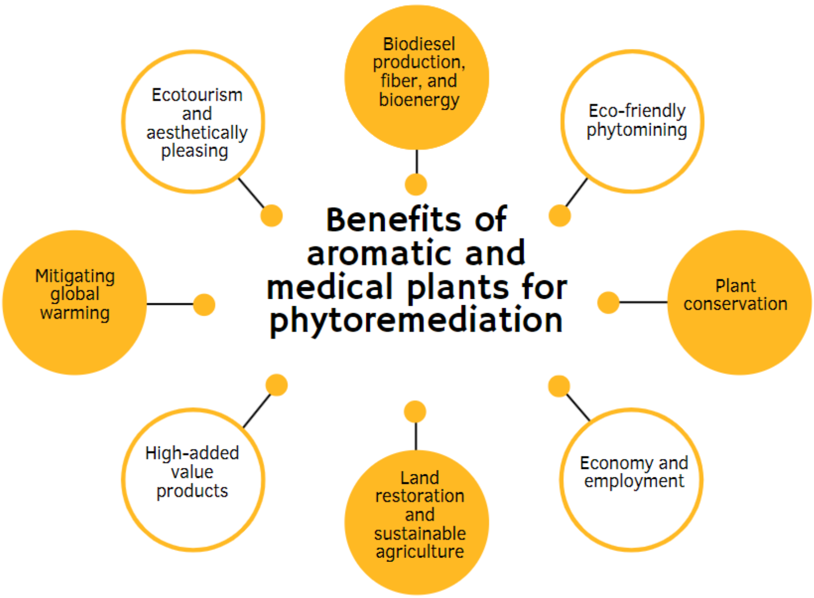

Figure 3: Benefits of Medicinal and Aromatic Plants for Sustainable Phytoremediation (Kumar et al., 2021; Mishra and Chandra, 2022)

Remediation of contaminated areas can be achieved by using different strategies by plant structure (Figure 4) (Rahimi et al., 2022). Each of these structures has a special importance for phytoremediation.

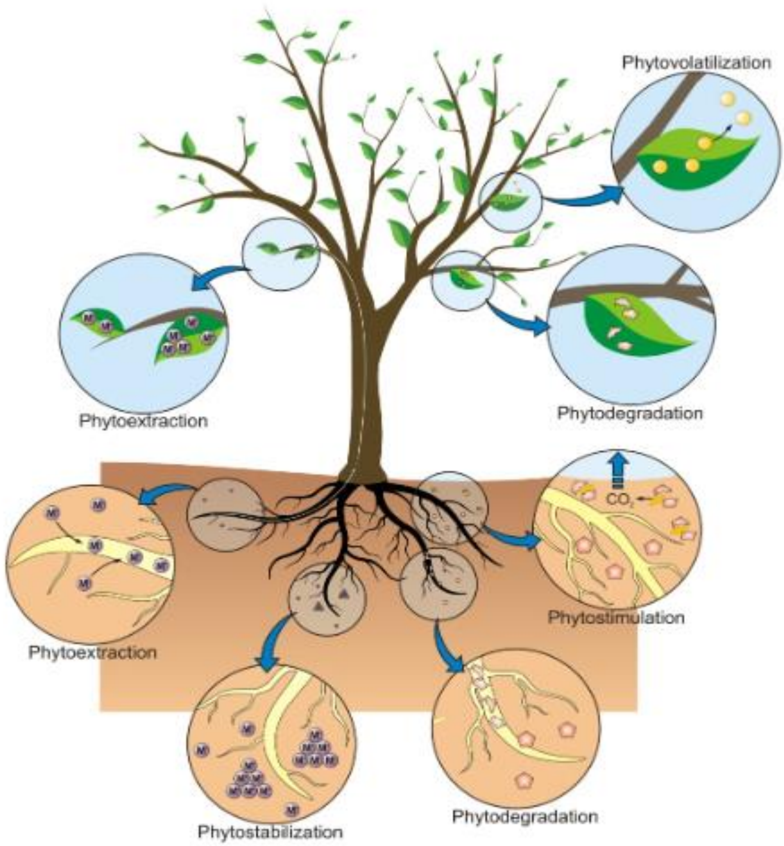

Figure 4: Different Phytoremediation Strategies Adapted by Aromatic Plants (J.C. Favas et al., 2014)

4. PHYTOREMEDIATION OF HEAVY METALS BY MEDICINAL AND AROMATIC PLANTS

Medicinal and aromatic plants are grown and commercially processed to obtain and process essential oils in their structures. Heavy metals absorbed by medicinal and aromatic plants during this process do not enter in the essential oils (Rahimi et al., 2022). A significant source of essential oil production is especially aromatic plants. The valuable oils obtained from here have a significant market share in the food processing, soaps, detergents, insect repellents, perfumery, cosmetic industry, and aromatherapy industries (Mishra and Chandra, 2022). It was observed that the percentage of essential oil increased gradually in some aromatic plants that were not seriously contaminated by heavy metals after heavy metal exposure. Due to the steam distillation technique applied to extract the essential oils in the structure of aromatic plants exposed to heavy metals, there are no dangerous heavy metals left in the oils. In this way, essential oils obtained from these aromatic plants used for phytoremediation may be acceptable in the marketplace (Wani et al., 2021; Mishra and Chandra, 2022).

Phytoremediation is not a stand-alone method. It is a holistic treatment mechanism consisting of the combination of different treatment strategies of the plant (Figure 4). Examples of studies using aromatic and medicinal plants in which different strategies are effective in phytoremediation are compiled in Table 2.

Table 2: Heavy Metal Removal with Different Phytoremediation Methods (Kumar et al., 2021). A: Aromatic, M: Medicinal plants

Phytoremediation method	Plants used	A/M	Contaminants
Phytostabilizer	*Dactylis glomerata* L.	M	As, Cd, Pb
	Chrysopogon zizanioides (L.) *Roberty* and *Vetiveria zizanioides* (L.) *Nash*	A/M	Cd, Pb, Cu, As, Hg, Fe, Cr, Ni, Sn, Zn
	Cymbopogon citratus (DC.) Stapf	A/M	Cd, Hg, Pb, Cu, Ni, Cr
	Cymbopogon winterianus Jowitt ex Bor.	A/M	Cd, Cr
	Ocimum basilicum L.	A/M	Cr, Cd, Ni, Pb, As, Zn
	Salvia officinalis L.	A/M	Cd, Pb, Cu
	Mentha × piperita L.	A/M	Pb, Ni, Cu, Cd
	Rosmarinus officinalis L.	A	Pb, As, Sb, Zn, Cu
	Zygophyllum fabago L.	M	Cd, Pb, Zn Cu
Rhizofiltration	*Helianthus annuus* L.	A	Radionuclides (Cs, U and Sr)
	Sagittaria montevidensis Cham. & Schltdl.	M	Al, V, Fe, As, Cu, Zn, Pb, Cd, Ni, Cr
	Eichhornia crassipes (Mart.) Solms	M	As, Cd Cr, Cu, Ni, Se
Phytoaccumulator	*Rosmarinus officinalis* L.	A	Ni. Hg, Pb, Cu, Zn, Cd, Ni, Fe, As, Sb
	Pelargonium roseum (Andrews) DC.	A	Cd, Ni, Pb, Zn
	Matricaria recutita (L.) Rauschert	A	Cd, Pb, Zn
	Portulaca oleracea L.	M	Cr
	Chrysopogon zizanioides (L.) Roberty	A	Mn, Cu
	Helianthus annuus L.	A	Pb, Cd, Zn, Cu, Fe, and As
	Cymbopogon martini (Roxb.) Wats.	A/M	Mn, Cu

Table 2 (Continued): Heavy Metal Removal with Different Phytoremediation Methods (Kumar et al., 2021). A: Aromatic, M: Medicinal plants

Phytoremediation method	Plants used	A/M	Contaminants
Phytodegradation	*Helianthus annuus* L.	A	Methyl benzotriazole
	Scirpus microcarpus J.Presl & C.Presl, *Phalaris arundinacea* L.	M	TNT, RDX
	Leucaena leucocephala (Lam.) de Wit	M	Tetrachloroethane (TCE), EDB
	Nicotiana tabacum L.	M	Perchlorate
	Canna indica L.	A/M	Simazine
	Arabidopsis thaliana (L.) Heynh.	M	TNT (2,4,6-trinitrotoluene)
	Kandelia candel (L.) Druce	M	Pyrene
	Chrysopogon zizanioides (L.) Roberty, *Phalaris arundinacea* L.	A/M	RDX, TNT
Phytostimulation	*Ceratophyllum deinersuin* L.	M	Atrazine
	Vetiveria zizanioides (L.) Nash, *Bidens pilosa* L., *Eleusine indica* (L.) Gaertn.	A/M	Petroleum hydrocarbons
	Ludwigia octovalvis (Jacq.) Raven	M	As
Phytovolatilization	*Nicotiana tabacum* L.	M	Methyl mercury
	Pteris vittata L.	M	As

The aromatic plant families Poaceae, Geraniaceae, Asteraceae, and Lamiaceae are the most effective ones for the phytoremediation of heavy metal-contaminated environments (Mishra and Chandra, 2022). Recently, due to their effectiveness, *Matricaria recutita* (chamomile), *Salvia officinalis* (sage,) and *Thymus vulgaris* (thyme) are recommended for phytoremediation (Kumar et al., 2021). These crops have high value with low input and can collect high amounts of toxic heavy metal in their tissues (Gupta et al., 2013). They can also take part in phytoremediation more successfully than other plants grown under the same conditions (Figure 5) (Bağdat and Eid, 2007). *Hypericum perforatum* L. (St. John's wort) for Cd and Cr, *Ocimum basilicum* L. (Basil), and *Beta vulgaris* L. cv. Fordhook Giant (Swiss chard) for Cu, Pb, and Zn and *Panax ginseng* for Cd, Pb, and Ni treatment have been used successfully in different studies (Bağdat and Eid, 2007).

Aromatic plants growing in heavy metal-contaminated areas can collect a remarkable quantity of toxic metals according to the level of pollution. Lydakis et al., (2016) studied with aromatic plants chamomile, sage, and thyme for their study. These plants flourish normally without showing any important morphological or physiological symptoms because of soil pollution, proving that they are tolerant of the wide concentration range of Cd, Pb, and Ni in the soil. Cultivation of medicinal and aromatic plants in heavy metal-contaminated areas will not provide complete cleaning of such areas but will provide a good solution. Of course, in such an area, besides certain heavy metals, other substances that may be more or less toxic can also be found in the soil. Such substances may damage the property and content of essential oils from aromatic plants. For this reason, a good soil analysis must be done before starting the cultivation of aromatic plants in a field contaminated with heavy metals. It is also an indisputable necessity to take all necessary precautions to avoid the consumption of aromatic plants by humans and animals.

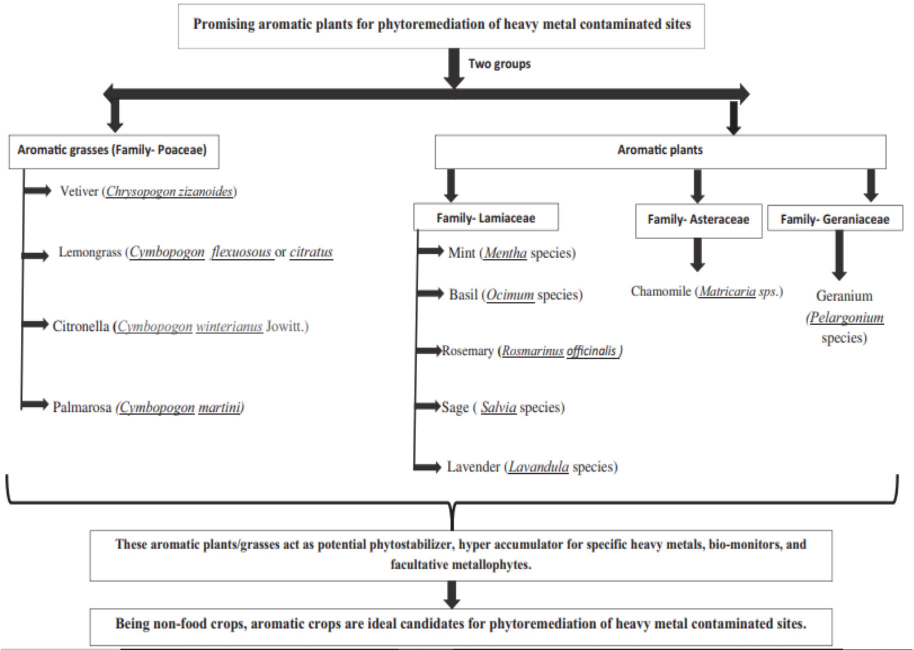

Figure 5: Encouraging Aromatic Plant Groups for Phytoremediation (Pandey et al., 2019)

5. CERTAIN MEDICINAL AND AROMATIC PLANTS HAVE HEAVY METAL ACCUMULATION

The research that has been done up to this point is reviewed in this section, along with the potential for phytoremediation and the efficiency of commonly grown medicinal and aromatic plants in removing heavy metals from the environment. This section reviews the research that has been done so far and looks at the phytoremediation potential of commonly grown medicinal and aromatic plants as well as the effectiveness of the medicinal and aromatic plants' ability to remove heavy metals from the environment. Table 3 presents the findings from the research that was conducted.

Table 3: Heavy Metal Removal with Medicinal and Aromatic Plants from Different Families (Lone and Gaffar 2021)

Name and family of the plant	Common name	Heavy metal
***Vetiver or Khus* (Family – *Poaceae*)**	The most widely known species are *Chrysopogon zizanioides* or *Vetiveria zizanioides*.	Cd, Pb, Cr, Zn, etc.
***Geranium* (Family − *Geraniaceae*)**	The most widely known species are *Pelargonium hortorum*, *Pelargonium roseum*, *Pelargonium graveolens*, etc. *Geranium* is the common name used for *Pelargonium* species.	Ni, Pb, and Cd
***Lemon Grass* (Family – *Poaceae*)**	The most widely known species are *Cymbopogon flexuosus* and *Cymbopogon citratus*.	Cu, Pb, Cr, Fe, Mn, As, Ni, etc. Mn, Fe, and Cu besides accumulating Cr, Zn, As, Cd, Ni, Pb, and Al
***Citronella* (Family – *Poaceae*)**	There are several species of citronella, and the widely known species of this plant is *Cymbopogon winterianus* Jowitt.	Cd, As, Fe, Ni, and Cu
***Palmarosa* (Family – *Poaceae*)**	Palmarosa is the common name for the species of *Cymbopogon martini*.	Cr, Ni, and Cd
***Mint* (Family – *Lamiaceae*)**	The most widely known species are *Mentha crispa* and *Mentha pulegium*. These species are popularly known as mint.	Cr, Cd, and Pb

Table 3 (Continued): Heavy Metal Removal with Medicinal and Aromatic Plants from Different Families (Lone and Gaffar 2021)

Name and family of the plant	Common name	Heavy metal
Rosemary **(Family – *Lamiaceae*)**	*Rosmarinus officinalis* is the well-known species of rosemary plant.	Pb, Zn, Cu, Cd, Ni, and Fe
Chamomile **(Family – *Asteraceae/Compositae*)**	Chamomile or camomile is the common name for several daisy-type plants of the Asteraceae family. The notable varieties of *Chamomilla* species include *Matricaria chamomilla* (German chamomile) and *Chamaemelum nobile* (Roman chamomile).	Cd, Cr, and Ni
Lavender **(Family – *Lamiaceae*)**	The most notable species of lavender is *Lavandula vera*.	Zn, Cd, and Pb.
Basil **(Family – *Lamiaceae*)**	The notable species of basil for phytoremediation methods include *Ocimum tenuiflorum* and *Ocimum basilicum*. Commonly known as the basil, the *Ocimum* species are used as phytostabilizers	Cr, Cd, and Pb
Sage **(Family – *Lamiaceae*)**	Sage is the common name used for *Salvia* species.	Cd, Pb, Zn, Cr, Ni, Fe

A lot of experiment and researches has been done in this area. The use of AMPs for treatment in heavy metal-contaminated areas was investigated. It has been revealed these plants are effective on which metal. An example of such research is given in Table 4.

Table 4: Medicinal and Aromatic Plants for the Phytoremediation of Different Heavy Metals (Pirzadah et al., 2019)

Plant	Metal	Plant	Metal
Cymbopogon citratus	Cd, As, Ni, Cu, Fe	*Vetiveria zizanioides*	Cd, Ni
Vetiveria zizanioides	Cd and Pb	*Cymbopogon citratus*	Ni
Ocimum basilicum	Cd	*Matricaria chamomilla*	Cd, Pb, Zn
Mentha arvensis	Cu, Zn	*Catharanthus roseus*	Cd, Pb, Ni, Cr
Vetiveria zizanioides	Cu, Pb, Sn, Zn	*Ocimum tenuiflorum*	As
Lemongrass	Pb, Cd, Zn	*M. chamomilla*	Cd, Pb
Euphorbia hirta	Cd	*Cymbopogon winterianus*	Cr
Cymbopogon citratus	Pb(II), Cd(II), Zn(II)	*Vetiveria zizanioides*	Cu, Zn, Pb
Ocimum basilicum	Cr, Cd	*Chrysopogon zizanioides*	Hg
Mentha crispa	Pb	*Aloe vera*	Cr
Mentha species	Ni, Cr, Cd, Al	*Ocimum basilicum*	Cr, Cd, Pb, Ni
Ocimum basilicum	Cd and Zn	*Pelargonium sps.*	Pb
Lavandula vera	Pb, Zn, Cd	*Hypericum sp.*	Cd
Rosmarinus officinalis	Cd and Pb	*Ocimum tenuiflorum*	Cr
Cymbopogon flexuosus	Cr	*Hypericum perforatum*	Cd
Euphorbia hirta	Radioactive waste	*Senecio coronatus*	Ni
Cymbopogon citratus	Pb	*Vetiveria zizanioides*	Cd, Ni
Ocimum basilicum	Cd, Pb, Zn	*Cymbopogon citratus*	Ni

Table 5 provides examples of research done with a different group of aromatic and medicinal plants that demonstrate phytoremediation capacity in addition to those presented in Tables 3 and 4 above. Table 6 lists the rate at which several aromatic and medicinal plants accumulate heavy metals.

Table 5: Promising Plants for Phytoremediation: Medicinal and Aromatic (Pruteanu and Muscalu, 2014; Lone and Gaffar, 2021; Hayat et al., 2022)

Name of the plant	Heavy metal	Name of the plant	Heavy metal
Aloe vera	Cr	*Hypericum perforatum*	Ni, Cr, Cd
Artemisia annua	As	*Matricaria chamomilla*	Ni
Bacopa monnieri	Fe	*Panax ginseng* Meyer	Cu
Brugmansia candida	Ag, Cd	*Phyllanthus amarus* Schum and Thonn	Cd
Catharanthus roseus	Cd, Pb, Ni, Cr	*Senecio coronatus*	Ni
Dioscorea bulbifera	Cu	*Trigonella foenum-graecum*	Cd, Co, Cr, Ni
Euphorbia hirta	Cd, radioactive waste	*Withania somnifera*	Cu
Thalspi caerulescens	Zn, Cd	*Artemisia vulgaris*	Zn, Cu, Pb, Cd, Ni
Catharanthus roseus	Cr	*Alyssum bertolonii*	Ni
Brassica juncea (indian mustard)	Se, Zn, Cu, Pb, Cd	*Mentha spicata*	Cr, Cu
Hypericum perforatum	Cu, Cd	*Hippophae rhamnoides*	Fe, Zn, Mn, Cu
Matricaria recutita	Cd, Zn	*Rinorea niccolifera*	Ni
Bacopa mannieri	Hg, Cd	*Aloe vera*	Cd, Cr, Pb, Co, Ag, Se, Hg
Achillea millefolium	Cu	*Cannabis sativa*	Pb, Cu, Zn, Cd, Ni
Salvia officinalis	Cd	*Urtica dioica*	Cr
Centaurea cyanus and Echinophora platyloba	Zn	*Taraxacum officinale*	Cd, Cu, Zn
Ocimum basilicum	Cd	*Astragalus racemosus*	Se
Centella asiatica and Orthosiphon stamineus	Zn, Cu, and Pb	*Cunila galioides Benth.*	Al
Pfaffia glomerata (Spreng)	Pb	*Mentha piperita*	As, Cd, Ni, Pb

Table 6: Heavy Metal Storage Capacity of Some Medicinal Plants (Nasim and Dhir, 2010; Fahimirad and Hatami, 2017)

Plant species	Heavy metal	Values
Amaranthus dubius	Cd	150 ppm
Amaranthus hybridus	Hg	336 ppm
Agave amaniensis	Cd	900 $\mu g\ g^{-1}$ dry wt
Costus speciosus	Cd, Pb	530 $\mu g\ g^{-1}$ dry wt
Matricaria chamomilla	Zn	271 $mg\ kg^{-1}$ dry wt
Ocimum tenuiflorum	Cr	419 $\mu g\ g^{-1}$ dry wt
Matricaria chamomilla	Zn	271 $mg\ kg^{-1}$ dry wt
Phyllanthus amarus	Cd	82 ppm
Hypericum sp.	Cd	0.5 $mg\ kg^{-1}$ dry wt
Cuminum cyminum	Fe	1.4 $mg\ g^{-1}$ dry wt
Bombax costatum	Fe	1.5 $mg\ g^{-1}$ dry wt
Hibiscus sabdariffa	Mn	243 $\mu g\ g^{-1}$ dry wt
Spilanthes oleracea	Zn	62.8 $\mu g\ g^{-1}$ dry wt
Bombax costatum	Zn	67.1 $\mu g\ g^{-1}$
Aesculus Hippocastanum	Pb	1480 $\mu g\ g^{-1}$
Tilia sp.	Zn	13.8–32.5 $mg\ kg^{-1}$
Sambucus nigra	Zn	30.8–49.9 $mg\ kg^{-1}$

5.1. Advantages of using AMPs for phytoremediation purposes

Phytoremediation is an aesthetically satisfactory mechanism that can reduce remediation costs and provide in-situ treatment/clean-up rather than burying pollution in-situ or moving the problem to another area.

With the help of green plants, this technology consists of a number of techniques for reducing, removing, degrading, or immobilizing environmental toxins. With inexpensive and readily available plants, the targeted metal can be significantly accumulated and tolerated (Şentürk et al., 2022). In addition to the treatment and cleaning process, more economical and sustainable results can be obtained when such plant species that produce large amounts of biomass for biofuel and energy production are used (Kumar et al., 2021).

Medicinal and aromatic plants have many different uses. For example, medicinal plants can be used for therapeutic purposes as well as for the elimination of environmental pollution as mentioned above (Figure 6) (Hayat et al., 2022). In addition, essential oils and secondary metabolism products obtained from these plants can meet the raw material needs of many industries such as pharma, perfumery, the cosmetic industry, and aromatherapy.

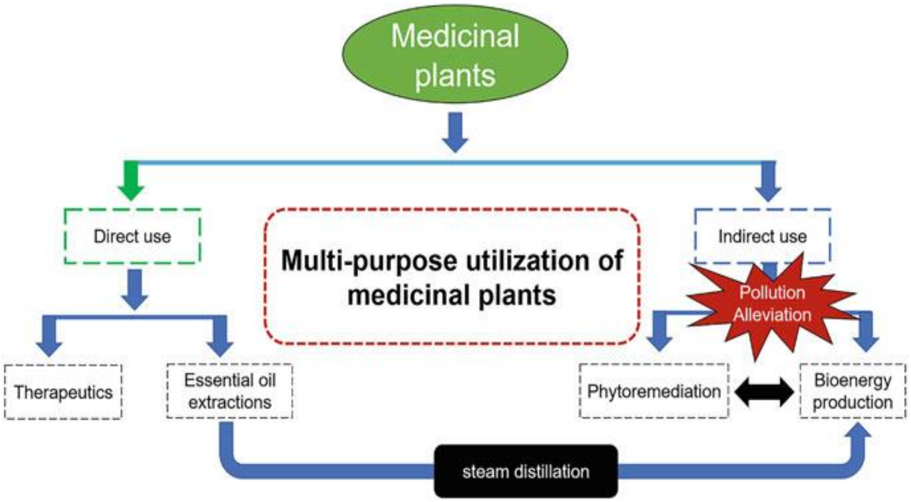

Figure 6: Multipurpose Uses of Medicinal Plants (Gupta et al., 2013; Hayat et al., 2022)

5.2. Disadvantage of Using AMPs for Phytoremediation Purposes

There are some disadvantages as well as possible advantages related to the use of AMPs for phytoremediation purposes. These are given below (Ali et al., 2013; Kumar et al., 2021):

- Phytoremediation using aromatic and medicinal plants gives results after a long period of time because the growth of plants takes a long time and plants with low biomass. It usually takes one or more harvest seasons for effective results.
- Since the treatment is limited to the depth that the roots of the plants can reach, it is not effective in very deep soil pollution.
- It is not widely used yet. Limited to pilot-scale field studies and research studies.
- Difficulty in mobilizing metal ions tightly bound to the soil.
- It is a more applicable method in low or moderately polluted areas, as plants will not grow due to toxic effects in heavily polluted areas.

CONCLUSIONS

The use of medicinal and aromatic plants instead of edible plants is an excellent solution for the remediation of heavy metal-contaminated sites. The advantage of this situation has been better understood recently. Phytoremediation by the use of aromatic and medicinal plants is, above all, a safe, environmentally friendly, economically viable, and sustainable approach. They also have an important market for aromatic oils, secondary metabolites, and bioenergy obtained from plants.

The only factor that compels practitioners here is time. It takes time for the plant to grow, and reach the desired plant biomass and the targeted phytoremediation potential. For more efficient and effective use of this method, methods and biotechnological approaches to solving these problems should be developed. Toxicity, which affects plant growth and survival at high metal concentrations, also inhibits the survival of local microorganisms in the contaminated area. It seems that more comprehensive biotechnological research is needed to fully and uninterruptedly benefit from the phytoremediation ability of AMPs.

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