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Review

Phytoremediation Potential of Ocimum Sanctum: A Sustainable Approach for Remediation of Heavy Metals

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Abstract: Plants have the ability to decrease the pollution level from the environment by absorbing inorganic/organic pollutants through their roots. After that, these pollutants are translocated or accumulated in less toxic forms in various parts of plants. This ability of plants is known as phytoremediation. It is an eco-friendly, and cost-effective approach for controlling environmental pollution. It can provide a sustainable way to improve the economics of developing countries. However, the biomass formed during this process can re-contaminate the environment through secondary pollutants. The contamination due to heavy metals (HMs) has become an environmental challenge globally. Metals such as cadmium (Cd), chromium (Cr), mercury (Hg), arsenic (As), nickel (Ni), lead (Pb), etc. can enter the water and soil largely through anthropogenic activities as well as other natural processes. After that, these metals pose a severe threat to living organisms. Due to their non-biodegradable nature, these metals can remain as such for a long time. These metals can initiate oxidative pressure in plants as a result affects agricultural production and yield. To mitigate this problem, phytoremediation has come forward as a safe, affordable, and ecologically sustainable solution than conventional physicochemical decontamination methods. Initially, several edible crops had been identified for the remediation. But at the present time, scientists are focusing on non-edible crops like aromatic/medicinal plants. There is no risk of food contamination by using these plants. This chapter describes the classification & uses of Tulsi and the phytoremediation mechanism of plants in detail.

Keywords: phytoremediation; aromatic plants; Ocimum sanctum (Tulsi); heavy metals (HMs)

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1. Introduction

Pollution is a major problem created due to rapid urbanization and industrialization (Suman et. al., 2018; Bhardwaj and Bharati, 2022; Bhardwaj, 2023). It may be due to organic and inorganic pollutants. Organic pollutants are usually xenobiotic to plants. Among various inorganic/organic pollutants, HMs contamination is posing a major threat to the environment and the health of humans/animals (Bolan et. al., 2014). Metals such as cobalt (Co), molybdenum (Mo), copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn) are critical for the growth of plants and are known as essential micronutrients. While other metals such as chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), uranium (U), cadmium (Cd), arsenic (As), and vanadium (V) are commonly found as contaminants and are known as non-essential nutrients for plants.

Metals are natural elements and are found in the earth's crust (Bhardwaj et. al., 2023). They cannot be degraded or destroyed but can accumulate in the food and in the living organism. They are very harmful and persist as such for a long time (Alam et. al., 2023). They have a high molecular weight, and the density is more than 5 g/cm^3. They can destroy cell membrane integrity, cause oxidative stress, inhibit photosynthesis, decrease plant chlorophyll, and interfere with nutrient uptake (Feng et. al., 2013).

Due to anthropogenic activities, HMs like Cr, Cd, Pb, Hg, As, Ni, etc. are continuously released into the environment and contaminate the water and soil (Mahar et. al., 2016). Several experts have

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reported the different sources of HMs like sludge from sewage (Farahat and Linderholm, 2015), use of fertilizers (Hamzah et. al., 2016), from gas and oil industries (Pichtel, 2016), metal smelting and mining (Chen et. al., 2016), electroplating and fossil fuel burning (Muradoglu et. al., 2015), usage of pesticides (Iqbal et. al., 2016). Essential and non-essential HMs are presented in Table 1 with their sources and associated health effects.

Table 1. Essential and Non-Essential HMs with their Sources and Health Effects.

S. No.	Classification of the HMs	Name of the HMs	Sources	Health Effects
1	Essential (harmless)	Copper (Cu)	Fungicides, paints, pigments, electroplating, & copper polishing	Metabolic activity abnormalities, abdominal disorders
2		Zinc (Zn)	Dyes, fertilizers, plumbing, oil refining	Gastrointestinal disorders, kidney & liver abnormal functioning
3		Iron (Fe)	High intake of iron supplements & oral consumption	Diarrhea, vomiting, abdominal pain, dehydration
4		Cobalt (Co)	Hip alloy replacement case	Cardiovascular, hepatic, endocrine, hematological
5	Non-Essential (toxic)	Arsenic (As)	Paints, pesticides, thermal power plants, fuel burning, smelting operations	Prostate cancer, liver cancer, leukemia, cardiac problems, urinary bladder cancer
6		Cadmium (Cd)	Fertilizers, batteries, e-waste, electroplating, plastic	Osteo-related problems, prostate cancer, lung cancer, breast cancer, renal cancer, gastric cancer
7		Chromium (Cr)	Leather tanning, dyes, industrial coolants, textile	Bronchitis cancer, Renal disorders
8		Lead (Pb)	Batteries, metal products, petrol additives, ceramics, coal combustion	Alzheimer's disease, nervous system disorder, lung cancer, carcinoma
9		Mercury (Hg)	Instruments, fluorescent lamps, hospital waste, electrical appliances, volcanic eruption, paper industry	Blindness, deafness, gastric problems, renal disorders, Minamata disease, sclerosis, skin cancer, brain cancer, colorectal cancer
10		Nickel (Ni)	Alloy, battery industry, mine tailing, thermal power plants	Nasal cavity cancer, lung cancer
11		Manganese (Mn)	Fertilizers, steel production, municipal wastewater discharges	Cardiovascular system disorder, central nervous systems disorder, respiratory systems disorder

Numerous techniques are available for the elimination of these poisonous metals from soil and water, such as chemical precipitation, membrane separation, reverse osmosis, electrodialysis, soil

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incineration, soil washing, solidification, excavation and landfill, and electric field (Wuana and Okieimen, 2011; Sreelakshmi, 2017; DalCorso et. al., 2019). But limited reports are present on these techniques because these techniques are not very effective, are expensive, and require high energy. Therefore, there is a requirement to develop efficient, cost-effective, and environmentally friendly remediation techniques.

Phytoremediation is a technique that is plant-based and uses plants to remove the pollutants such as pesticides, metals, crude oil, explosives, and solvents. Alkorta et. al., (2004) discussed different types of phytoremediation techniques such as phytoextraction, phytofiltration, phytostabilization, phytovolatilization, phytodegradation, rhizodegradation, and phytodesalination. Phytoremediation is a low-cost, effective, sustainable, and naturally friendly technique. This technique has been used successfully at the site of metal mining and PCB dumping sites. Researchers used different plants such as alpine pennycress, mustard plants, pigweed, and hump for the removal of pollutants (Takahashi, 2009; Pantola et. al., 2014). Lone et. al., (2008) stated that due to the differences in physiology, all plants are not able to accumulate HMs or organic pollutants. Now, this technique is popular in public as green clean, and it is used as an alternative of chemicals.

Meagher (2000) described the biophysical and biochemical processes of the plants and stated that adsorption, transport and translocation, hyperaccumulation or transformation, and mineralization, can remediate the HMs. Lots of data are existing on the remediation of HMs with edible crops. But the practice of edible crops for remediation purposes is not practicable because the HMs enter into crops and then can transfer into humans/animals after consumption of food. HMs affect the protein, fat, and carbohydrate constituents of edible plants (Khan et. al., 2015). Reactive oxygen species (ROS) were reported in living organisms due to HMs pressure (Rehman et. al., 2018).

Now scientists are worried about the health of humans/animals. They recommend the aromatic/medicinal plant as a novel selection for the remediation of HMs (Figure 1). The HMs do not enter the food chain through these plants because these plants are non-edible due to their essence. Humans/animals do not consume these plants directly like edible plants. In fact, the availability of these plants is high, and they are ecologically feasible. Lubbe and Verpoorte (2011) stated that these plants are grown to produce personal care products (PCPs), cosmetics, essential oils, and Ayurvedic medicine.

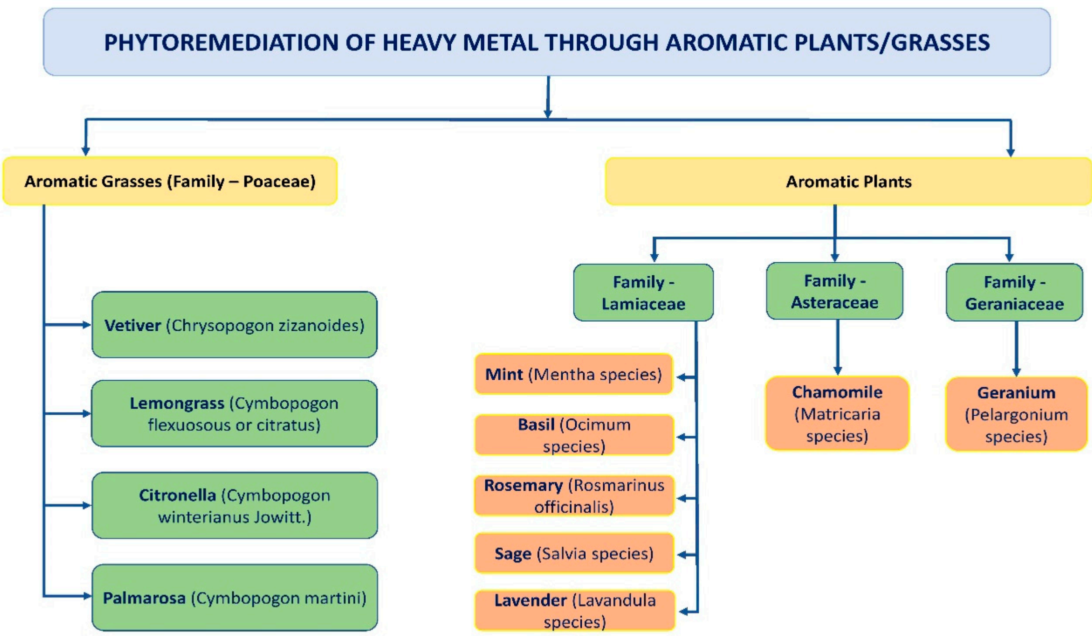

Figure 1. Different Aromatic Plants/Grasses for the Phytoremediation of HMs.

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Essential oil is a high-value product that is widely used as an aromatic agent in several industries, and it is free from the danger of metal accumulation. Pandey et. al., (2019) stated that there is no change in oil constituents by growing these plants in the contaminated sites. These aromatic/medicinal plants absorb metals through the roots and accumulate them in the different parts of the plants (Zheljazkov and Warman, 2004). These plants have high value with short input.

Ocimum sanctum L. is commonly known as Tulsi and belongs to the Lamiaceae family. It has two varieties i.e. Black (Krishna Tulsi) and green (Rama Tulsi). Tulsi is a Sanskrit word that means 'matchless one'. It is called by names like Rama Tulsi, Krishna Tulsi in Sanskrit, and Holy Basil in English. It is also known as an avatar of Lakshmi and may be planted in front of houses or temples. It is a perennial, erect, many-branched plant. The height of this plant varies from 30 to 60 cm. It is mostly found in the Indian subcontinent. As per the study of Flood (2008), the worship of the Tulsi includes the lighting of the lamps in Kartik months. The followers of Lord Vishnu known as Vaishnavas bear the Tulsi. Pawar and Patil (2008) stated that the vivah of Tulsi is a festival, and performed in Prabodhini Ekadashi, and Kartik Purnima.

Several contents such as ursolic acid, oleanolic acid, eugenol, rosmarinic acid, β-caryophyllene, carvacrol, terpinene-4-ol, α-pinene, β-pinene, α-camphor, methyl chavicol, limatrol, and linalool are present as chemical composition in the Tulsi (Pattanayak et. al., 2010; Sundaram et. al., 2012). Eugenol (1-hydroxy-2-methoxy-4-allylbenzene) is present as the main part (~ 70 %) in the oil of Tulsi (Padalia and Verma, 2011) (Figure 2). In this chapter, we are discussing the uses & classification of Tulsi and the phytoremediation mechanisms of plants.

Classification: Kingdom- Plantae; Division- Magnoliophyta; Class- Magnoliopsida; Order- Lamiales; Family- Lamiaceae; Genus- Ocimum; Species- O. Tenuiflorum

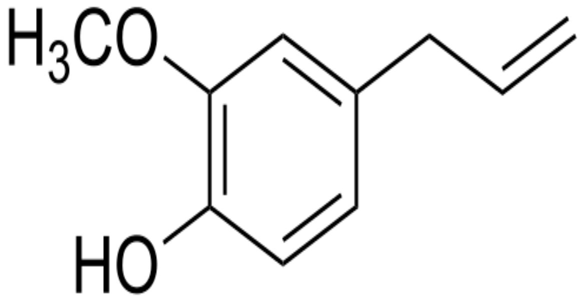

Figure 2. Molecular Structure of Eugenol.

2. Uses of Ocimum Sanctum (Tulsi)

It is a noteworthy source of medicine and is used for religious purposes also. It is commonly used in Ayurveda, Siddha, and Unani systems of medicine for the treatment of cough, diarrhea, headaches, asthma, dysentery, fever, eye diseases, arthritis, heart disease, gastric ailments, indigestion, inflammatory diseases, etc. (Braun and Cohen, 2015). The medicinal use of Tulsi is very old. China used the first natural herbal preparations as medicines. It has been used for its healing properties or therapeutic potential from thousands of years. It has anticancer, antifertility, antifungal, antidiabetic, hepatoprotective, antimicrobial, antiemetic, cardioprotective, analgesic, antispasmodic, antimalarial, adaptogenic, diaphoretic, antipyretic, antistress properties, anti-inflammatory properties, etc. It helps in preventing diabetes and signs of aging through its antioxidant activity. It involves retaining skin moisture levels, reducing skin roughness and scaliness, preventing wrinkles, and making the skin smooth. Traditionally, Tulsi is taken in many forms, as herbal tea, dried powder, or fresh leaf. Dried leaves of Tulsi are used to repel insects after mixing with grains (Biswas and Biswas, 2005).

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3. Health Effects of HMs

Sarwar et. al., (2010) studied the toxic properties of metals on living organisms and stated that these metals can enter the body of humans through contaminated food. After entering the body, these metals accumulate through biomagnification and can affect diverse body systems like the immune system, nervous system, and renal system. Vascular damage, cancer, and birth & gastrointestinal defects are examples of the complications of HMs toxicity (Costa, 2019; Gazwi et. al., 2020). HMs are teratogenic and endocrine disruptors (Mahar et. al., 2016). Pandey and Madhuri (2014) stated that these metals can interfere with metabolism. Exposure to high doses may cause abdominal colic pain, kidney failure, and bloody diarrhea (Tsai et. al., 2017) while low-dose exposure can cause anxiety, fatigue, and harmful effect on the brain of children (Mazumdar et. al., 2011). As, Cd, and Cr can disrupt DNA synthesis and repair (Koedrith et. al., 2013).

4. Mechanism of Phytoremediation

Phytoremediation is the least destructive remediation method and helps to sustain the natural condition of the environment (Figure 3). Numerous studies have been done on this technique with the different plant species and are shown in Table 2.

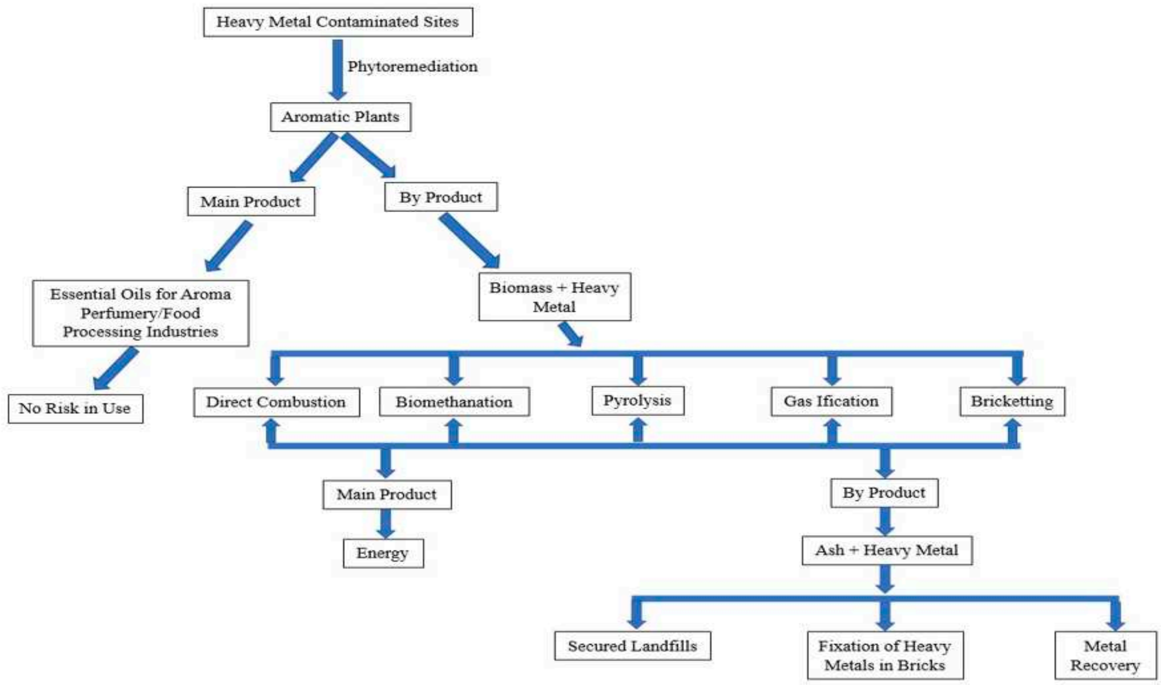

Figure 3. A Diagram Showing to Introduce the Novel Approach for Sustainable Phytoremediation.

Table 2. Phytoremediation of Different HMs with Different Plant Species.

S. No.	HMs	Name of the Plant	References
1	Hg	Chrysopogon Zizanioides	Mangkoedihardio and Triastuti, 2011
2	Cu, Pb, Sn, Zn	Vetiveria Zizanioides	Vo and Nguyen, 2011
3	Cd	Rosmarinus Officinalis	Tapia et. al., 2011
4	Cu, Zn, Pb	Vetiveria Zizanioides	Chen et. al., 2012
5	Multi metals	Pelargonium Roseum	Shahid et. al., 2012
6	Cr	Vetiveria Zizanioides	Sinha et. al., 2013
7	Pb, As, Sb, Zn, Cu	Rosmarinus Officinalis	Affholder et. al., 2013
8	Pb	Matricaria Chamomilla	Farzadfar et. al., 2013
9	Cd, Pb, Zn	Ocimum Basilicum	Stancheva et. al., 2014

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10	Multi metals	Salvi Officinalis	Stancheva et. al., 2014
11	Cd, Ni, As, Pb	Vetiveria Zizanioides	Gunwal et. al., 2014
12	Ni	Cymbopogon Citratus	Lee et. al., 2014
13	Pb, Cd, Zn	Chrysopogon Zizanioides	Adigun and Are, 2015
14	Multi metals	Cymbopogon Martini	Pandey et. al., 2015
15	Multi metals	Pelargonium Graveolens	Chand et. al., 2015
16	Cd, Zn	Ocimum Basilicum	Akoumianaki-Ioannidou et. al., 2015
17	Cd, Pb	Rosmarinus Officinalis	Ramazanpour, 2015
18	Multi metals	Salvia Sclarea	Chand et. al., 2015
19	Pb, Zn, Cd	Lavandula Vera	Angelova et. al., 2015
20	Cd	Ocimum Basilicum	Nazarian et. al., 2016
21	Pb, Cd, Zn	Cymbopogon Citratus	Babarinde et. al., 2016
22	Multi metals	Mentha Arvensis	Anwar et. al., 2016
23	Multi metals	Rosmarinus Officinalis	Boechat et. al., 2016
24	Cd, Pb	Vetiveria Zizanioides	Ng et. al., 2017
25	Multi metals	Chrysopogon Zizanioides	Gautam et. al., 2017
26	Cu, Zn	Mentha Arvensis	Malinowska and Jankowski, 2017
27	Cd	Ocimum Basilicum	Alamo-Nole et. al., 2017
28	Pb, Cd	Helianthus Annuus	Alaboudi et. al., 2018
29	Cd	Virola Surinamensis	Andrade Junior et. al., 2019
30	Cd	Glycine Max, Helianthus Annuus	Wang et. al., 2022
31	Pb	Scirpus Grossus	Tangahu et. al., 2022

Milic et. al., (2012) stated that phytoextraction is the best phytoremediation technique for the removal of HMs from contaminated sites. The efficiency of this technique depends on the properties of soil, plant species, and the bioavailability of the HMs. Accumulated HMs should be translocated from the roots to shoots. The concentration of HMs in shoots and the biomass of shoots are the main key factors for the phytoextraction potential (Li et. al., 2010). Ali et. al., (2012) reported that those plants are more suitable for phytoextraction and have multiple harvesting cuts in a single period of growth. While Malik et. al., (2010) reported that those plants are more suitable than trees and shrubs which have higher adaptability to stress, higher biomass production, and a high rate of growth.

***Uptake and Translocation Mechanism of HMs*:** In this procedure root uptake, mobilization, xylem loading, accumulation, root-to-shoot transport, and cellular compartmentation are involved. This process is mediated by complexing agents and metal ion transporters. H^+-coupled carrier proteins or transporters are present in the membrane of the root cell and play a significant role in the uptake of metal ions. Mostly, metals are not easily available due to existing in the soil as insoluble forms. Dalvi and Bhalerao (2013) stated that plants can increase the bioavailability of HMs by releasing root exudates. Jacob et. al., (2018) described the accumulation, modulation, and absorption of HMs from the soils to plants.

HMs are absorbed by the root from polluted soil and move across the root cells. There are two pathways for the uptake of these metals into the roots **(i)** Apoplastic pathway (AP) and **(ii)** Symplastic pathway (SP). AP is known as passive transport while SP is known as active transport. Peer et. al., (2005) stated that SP is dependent on energy. They described that HMs can form complexes with chelators after entering into the root. These complexes, including sulfate, phosphate, and carbonate are precipitated and then restrained in the intracellular spaces or extracellular spaces (Ali et. al., 2013). These complexes act as metal ligands to facilitate the chelation of metallic ions. Citrate is the chief chelator for metals like Ni and Fe. After that, these metals are transferred to the harvestable portions of the plants (Meagher, 2000).

Thakur et. al., (2016) stated that metal ions are transferred from the vacuoles of the root to the xylem and then transferred from the xylem to shoot via xylem vessels. Tong et. al., (2004) studied the transportation and distribution mechanism of HMs in the plants and stated that these metals are transported and then distributed in the leaves through symplast or apoplast. DalCorso et. al., (2019)

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stated that metals are transported from roots to shoots through the transport mechanism. Sreelakshmi (2017) studied the potential of Ocimum Sanctum of Fe and Pb removal from the wastewater and stated that the % of metal removal increased with the increase of Tulsi leaves dosage.

Calculation:

$$\%\ \text{of HMs removal} = \frac{\text{Initial (I)-final (F) concentration of metal}}{\text{Initial (I) concentration of metal}} \times 100$$

5. Limitation of Phytoremediation

This is the best technique for the removal of HMs but has some limitations.

(i) This technique requires more time.
(ii) The efficiency of this technique is less due to the slow growth rate of plants and less production of biomass.
(iii) The mobilization of some metals is less due to tightly bound metal ions.
(iv) There is a risk of contamination of the food chain due to the lack of proper care.

6. Conclusions and Recommendations

HMs like Cr, Pb, Fe, Cd, Ni, Cu, etc. are released from several industries like the iron industry, cement industry, metallurgical industry, etc. These metals are removed by several techniques like chemical precipitation, electrochemical treatments, physico-chemical methods, coagulation and flocculation, membrane filtration, ion exchange, electrodialysis, etc. The use of aromatic plants/medicinal plants is the more eco-friendly and cost-effective technique for the removal of HMs from contaminated sites. These plants have an excessive potential for phytoremediation to eliminate HMs. These plants act as metallophytes, hyperaccumulators, phytostabiliser, and bio-monitors. These plants extract HMs from the soil and convert them into less poisonous forms and give economic benefits. The percentage of essential oil increases when the aromatic/medicinal plants grow in polluted sites.

The non-edible characteristic and essential oil make the aromatic/medicinal plants suitable crops for the remediation of HMs. The high production and export of oil can be supportive of the progress of any nation. Remediation through plants is the sustainable approach than other methods. Because it does not harm the biological and physical properties of the soil.

Tulsi validates the many physiological benefits and is used in tea. It is used also for spiritual purposes. The farming of Tulsi is not only for the benefit of individuals while it has social and environmental impacts. There are several recommendations which are as follows:

(i) Long-term monitoring is required for the assessment of risks which are involved with the phytoremediation.
(ii) More research is required to relate to the phytoremediation potential of medicinal/aromatic plants, which may lead to the development of "Green scented technology" in the future.
(iii) This technique should be commercialized on a huge scale. So that it will ensure food security in a sustainable way for making the earth a more beautiful place to live.

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