



A GREEN APPROACH TO ENVIRONMENTAL REMEDIATION: THE POTENTIAL OF *LANTANA CAMARA* AND *SENNA UNIFLORA*

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Abstract: Heavy metal(HM) contamination of soil near industrial sites and waste disposal grounds is a major environmental concern. Phytoremediation, a sustainable and eco-friendly approach, involves the use of green plants to remove, stabilize, or detoxify hazardous heavy metals from polluted environments. This strategy relies on hyperaccumulator plant species that exhibit exceptional tolerance to elevated HM concentrations. This study investigates the potential of *Lantana camara*(LC) and *Senna uniflora* (SU) for heavy metal accumulation through Fourier Transform Infrared Spectroscopy(FTIR) analysis. FTIR was conducted on the root, stem, fruits(only LC) and leaf tissues of both plant species to identify functional groups involved in metal binding. In this paper, the potential of *Lantana camara*(LC) and *Senna uniflora* (SU) for the remediation of heavy metals was investigated through a controlled pot experiment using contaminated soil. The polluted soil sample and plant extract were first analyzed using UV-Spectroscopy to determine the peak absorbance, indicating the presence of HM in the samples. The concentrations of eight HM: Cadmium(Cd), Lead(Pb), Copper(Cu), Zinc(Zn), Mercury(Hg), Nickel(Ni), Chromium(Ch), and Arsenic(As) — were analyzed in plant extract using FTIR Spectroscopy. The results revealed significant shifts in peaks corresponding to hydroxyl(–OH), carbonyl(C=O), carboxylate(COO[–]), and amine(–NH) groups, indicating their active role in heavy metal coordination. Comparative analysis showed that LC exhibited more pronounced changes in functional group intensities, particularly in the roots, suggesting higher metal-binding efficiency. In contrast, SU demonstrated moderate shifts, with notable involvement of carboxyl and hydroxyl groups. These findings highlight the ability of both plants to accumulate HM, with LC showing greater potential for phytoremediation applications, which would be beneficial for improving both the environmental and human-health in affected areas.

IndexTerms: Heavy metals, phytoremediation, *Lantana camara*, *Senna uniflora*, Fourier Transform Infrared Spectroscopy (FTIR).

I. INTRODUCTION

Environmental pollution by heavy metals has become a serious problem in the world. The mobilization of heavy metals through extraction from ores and subsequent processing for different applications has led to the release of these elements into the environment [1]. Since the beginning of the industrial revolution, heavy metal contamination of the biosphere has increased considerably and became a serious environmental concern. Contamination by heavy metals can be considered as one of the most critical threats to soil and water resources as well as to human health [2]. Many cities around the world face challenges in managing solid waste, including the disposal of hazardous waste like infectious materials, toxic substances, and heavy metals or radioactive materials. A major environmental concern due to dispersal of industrial and urban wastes generated by human activities is the contamination of soil. Controlled and uncontrolled disposal of waste, accidental and process spillage, mining and smelting of metalliferous ores, sewage sludge application to agricultural soils are responsible for the migration of contaminants into non-contaminated sites as dust or leachate and contribute towards contamination of our ecosystem [3]. The soil forms an integral part of our agricultural resource and plays a vital role in green revolution and food security. Due to rapid urbanization and industrialization, agricultural lands have become increasingly contaminated by organic, inorganic and metallic pollutants [4]. This affects the ecosystems, surface, subsurface, ground water, food quality and health [5]. Soil microorganisms can degrade organic contaminants, while metals need immobilization or physical removal. Although many metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by formation of free radicals. Another reason why metals may be toxic is that they can replace essential metals in pigments or enzymes disrupting their function [6]. Thus, metals render the land unsuitable for plant growth and destroy the biodiversity.

Heavy metals are obtained from natural and anthropogenic sources. Naturally, heavy metals are associated with the volcanic eruption, wind erosion, forest fire and fossil fuel usage in general. The metals from the natural sources cause less harm to environment in general, whereas the metals from anthropogenic sources (**Table 1**) such as smelters, thermal power plants, mines, foundries pose a threat to man-kind [7]. Heavy metals refer to some metals and metalloids possessing biological toxicity, such as cadmium, mercury, arsenic, lead, and chromium. Remediation using chemical, physical, and biological methods has been adopted to solve the problem. Phytoremediation basically refers to the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environments [8]. It has proven to be a promising alternative to conventional approaches as it is cost effective, environmentally friendly, and aesthetically pleasing. the natural ability of extraction, approximately 500 taxa have been identified as hyperaccumulators of one or more metals [9].

Table 1: Anthropogenic Sources of Heavy Metals in the Environment.

Source	Activities/Processes	Major Heavy Metals Released
Industrial Activities	Mining and smelting of metal ores	As, Cd, Pb, Hg
	Metal manufacturing and plating	Cr, Ni, Zn
	Chemical industries (pigments, solvents, catalysts)	Pb, Cr, Cu
Agricultural Practices	Use of phosphate-based fertilizers	Cd, As, Pb
	Application of pesticides and fungicides	As, Cu, Zn
	Sewage sludge application in farmlands	Hg, Pb, Cd
Municipal Solid Waste	Improper waste disposal (landfills, dumping)	Pb, Hg, Cd
	Leachate from landfills	As, Zn, Cr
Urbanization and Traffic	Vehicular emissions (brake wear, tire debris)	Pb, Cd, Cu, Zn
	Use of leaded fuels	Pb
Energy Production	Coal combustion (power plants)	Hg, As, Cr
	Oil refining	Ni, V
Wastewater and Sewage	Industrial wastewater discharge	Pb, Cr, Cd
	Municipal sewage	Hg, Pb, Cd
Electronic Waste (E-Waste)	Improper disposal of electronics (batteries, PCBs)	Hg, Pb, Cd
Construction Activities	Cement production and building demolition	Cr, Pb, Zn
Mining Activities	Excavation, ore extraction, and tailing disposal	Pb, As, Cd, Zn

Phytoremediation is a rapidly advancing technology that can be applied to a wide range of pollutants, including both organic and inorganic contaminants, in soil, water, and air. However, the capacity of plants to accumulate heavy metals varies greatly between species and even among different cultivars within the same species. This variation is due to the unique genetic, morphological, physiological, and anatomical characteristics of each species, which influence their mechanisms of ion uptake. There are several distinct categories of phytoremediation, each utilizing different remediation mechanisms, including the removal of pollutants through plant roots, stabilization of pollutants in the soil, and degradation of pollutants through plant-based processes [10]. Based on the processes of phytoremediation involved in the remediation of toxic contaminants from soil and water, the overall mechanisms of phytoremediation including phytovolatilization (release of contaminants into the atmosphere), phytoextraction (uptake and chelation of metals), phytodegradation (breakdown of contaminants by plant enzymes), rhizodegradation (breakdown of contaminants by root-associated microbes), phytostabilization (immobilization of contaminants in the soil), rhizofiltration (uptake and retention of contaminants by roots), and phytodesalination (uptake of mineral ions) [11].

II. GENERAL DESCRIPTION

2.1 *Lantana camara*:

Lantana camara, also known as wild sage, is a thorny multi-stemmed, deciduous shrub with an average height of 2m (6ft). The shrub's taxonomic position is defined as belonging to the class of magnoliopsida, order lamiales, family verbenaceae and genus *Lantana*. Stems are square in outline, covered with bristly hairs when green, often armed or with scattered small prickles (**Figure 1a**). *Lantana camara* possesses a strong root system (**Figure 1b**). The roots even after repeated cuttings give new flush of shoots. Leaves are opposite, simple, with long petioles, oval blades which are rough and hairy and have blunt toothed margins (**Figure 1c**). The leaves of *Lantana camara* have a strong aroma. Its flowers are small, multi-colored, in stalked, dense in flat-topped clusters with a corolla having narrow tube with four short spreading lobes (**Figure 1d & e**). Their flowers undergo color change subsequent to anthesis. These flowers occur in cluster which includes white-pink-lavender or yellow-orange-red mix. The yellow coloration of the flower provides visual cue to pollinators and change in color is initiated on the act of pollination. Berries of *Lantana camara* are round, fleshy, 2-seeded drupe with initially green in color and turning purple and finally to blue-black color (**Figure 1f**). However, the berries are very poisonous in nature though these are attractive to insects and birds. Seeds germination is easy and faster in *Lantana camara* [12].

2.2 *Senna uniflora*:

Senna is a large genus of flowering plants in the legume family (Fabaceae, subfamily Caesalpinioideae,[13] tribe Cassieae ser. Aphyllae [14]). This diverse genus is native throughout the tropics, with a small number of species in temperate regions. The number of species is estimated to be from about 260[15] to 350.[16] The type species for the genus is *Senna alexandrina*. About 50 species of *Senna* are known in cultivation [17]. Plants in the genus *Senna* are shrubs, sometimes small trees or perennial herbs. The leaves are arranged alternately, paripinnate with up to 25 pairs of leaflets, each leaf with a stipule at the base, but that often falls off as the leaves mature. The flowers are arranged in racemes in leaf axils with bracts at the base. The flower has five egg-shaped green or yellowish sepals and five usually yellow, usually glabrous petals. There are usually ten stamens that are free from each other, the filaments of

different lengths, and some are staminodes. The fruit is a leathery pod containing several seeds [18][19][20][21] (as depicted in Figure 2).

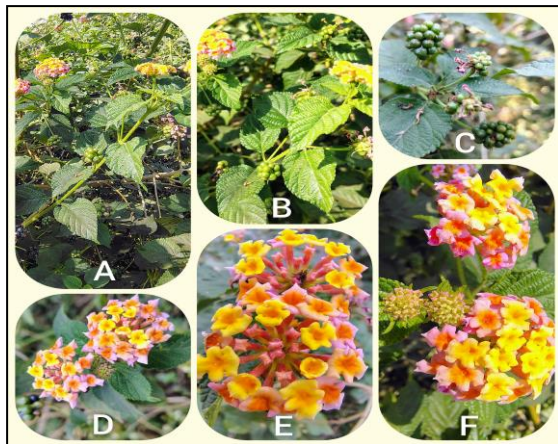


Fig.1: Characteristics of *Lantana camara*

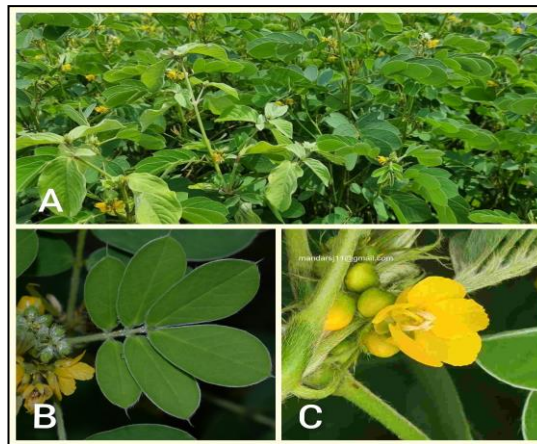


Fig.2: Characteristics of *Senna uniflora*

This study focuses on evaluating the phytoremediation potential of *Lantana camara* and *Senna uniflora* for heavy metal-contaminated soils. By analyzing the uptake and accumulation mechanisms through techniques such as Fourier Transform Infrared **Spectroscopy (FTIR)** and **UV-Spectroscopy**, this research aims to identify the functional groups and quantify the concentrations of heavy metals accumulated in plant tissues. The findings of this study will provide valuable insights into the mechanisms of heavy metal absorption and highlight the potential of these species as effective candidates for soil remediation, offering a sustainable solution to mitigate heavy metal contamination.

III. MATERIALS AND METHODS

3.1 Collection of Samples:

Plant and soil samples were obtained from Shajapur, Waluj (19.8746° N, 75.2173° E), Chhatrapati Sambhaji Nagar, Maharashtra, India. The collected samples included *Senna uniflora* (HS1-SU) and *Lantana camara* (HS2-LC). The plants were carefully uprooted by excavating the surrounding soil, ensuring the roots remained intact. Soil samples were collected from a depth of 15 cm below the surface (mentioned in Figure 3). The collected plant samples were subsequently identified and their species confirmed based on morphological characteristics at the Department of Botany, Deogiri College, Chhatrapati Sambhaji Nagar. This step ensured accurate species classification for subsequent analysis.

3.2 Extraction of Samples:

Soil and plant samples were collected and prepared following rigorous protocols to ensure accurate analysis. Soil samples were gathered at different depths, including surface soil (0–15 cm) and subsoil (15–30 cm), to align with the study's objectives. Approximately 500 grams of soil were collected from each sampling location using clean, non-metallic instruments, such as plastic or stainless-steel trowels, to prevent contamination. The samples were stored in labelled bags (HS1-LC and HS2-SU), placed in clean plastic containers, and kept in a cool, dry location until further examination. The soil samples were air-dried at room temperature for several days on clean trays, protected from direct sunlight and high temperatures. Once dried, the samples were passed through a 2 mm mesh to remove larger particles, stones, and organic debris, retaining the fine soil fraction for analysis. To ensure homogenization, some samples were ground into a fine powder using a mortar and pestle or a mechanical grinder (as depicted in Figure 4). Heavy metals were extracted using a robust acid digestion technique, wherein 0.5–1.0 grams of dried and sieved soil were precisely weighed into Teflon or PTFE digestion containers. A 3:1 mixture of concentrated nitric acid (HNO₃) and hydrochloric acid (HCl) (aqua regia) was added, and the samples were heated on a hot plate or in a microwave digestion system at 120–150°C until fully digested, producing a clear solution. After cooling, the digested mixture was transferred to a volumetric flask and diluted to a specific volume with deionized water. Any remaining particulates were filtered using Whatman filter paper, and the clear extracts were analyzed for heavy metals using UV-Vis spectroscopy.

Plant samples, including roots, stems, leaves, and fruits, were collected from the targeted area using clean, non-metallic tools to prevent contamination. The samples were stored in sterile, labelled plastic bags. Before processing, the samples were extensively washed with tap water to remove surface impurities such as soil, dust, and debris and then rinsed with distilled water to eliminate residual contamination. The cleaned samples were dried in an oven at 60–80°C until reaching a stable weight, typically within 48–72 hours. The dried samples were ground into a fine powder using a non-metallic grinder to ensure uniformity and stored in labelled centrifuge tubes as follows: HS1-LC (Leaves: HLC-L, Stems: HLC-S, Fruits: HLC-F) and HS2-SU (Leaves: HSU-L, Stems: HSU-S, Roots: HSU-R) (as depicted in Figure 5). A representative sample of the ground material, weighing approximately 0.5–1.0 grams, was weighed precisely with an analytical balance for further processing. For digestion, the plant powders were placed into clean digestion containers, and 5–10 mL of concentrated nitric acid (HNO₃) was added, with an optional small quantity of hydrogen peroxide (H₂O₂) or perchloric acid (HClO₄) to aid in breaking down resilient plant material. The mixture was gradually heated on a hot plate or in a microwave digestion apparatus at 120–150°C until fully digested, resulting in a clear solution after 1–3 hours. Once cooled, the digested solutions were diluted to a specific volume, typically in 50- or 100-mL volumetric flasks, with distilled water. Any particulates were filtered using Whatman filter paper, and the solutions were analyzed using UV-Vis spectroscopy at the Biotechnology Department of Deogiri College, Chhatrapati Sambhajnagar. Additionally, the powdered plant samples were sent to the Chemical Department at Dr. Babasaheb Ambedkar Marathwada University for Fourier Transform Infrared (FTIR) spectroscopy analysis.

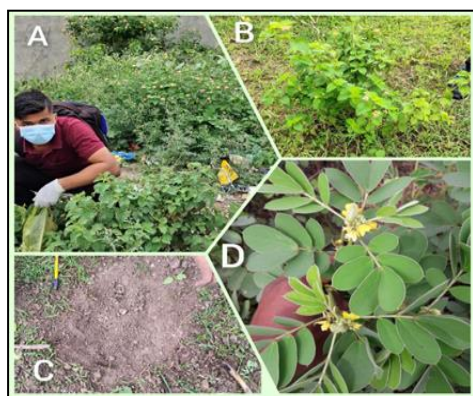


Fig.3: Collection of Soil and Plant Samples

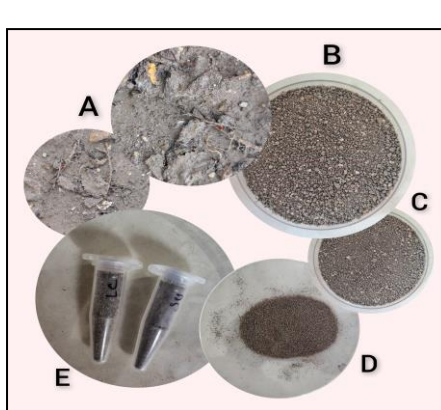


Fig.4: Preparation of Soil samples for Analysis (HS1-LC and HS2-SU).



Fig.5: Powdered of *Lantana camara* (A, B, C) and *Senna uniflora* (D, E, F) plant.

IV. ANALYSIS OF SAMPLES

4.1 UV-Vis Spectroscopy:

UV-VIS Spectroscopy refers to the analytical assessment of various kinds of solvents and materials. Spectroscopy is typically favored, particularly by small-scale industries, due to the lower equipment costs and minimal maintenance issues. The analytical technique relies on assessing the absorption of monochromatic light by colorless substances within the near ultraviolet range of a spectrum (200-400nm). Ultraviolet (UV) spectroscopy is an optical spectroscopy physical technique that employs light in the visible, ultraviolet, and near-infrared ranges. Therefore, for a set path length, it can be utilized to ascertain the concentration of the absorber in a solution needed to understand how quickly the absorbance varies with concentration [22, 23]. A molecule or ion will exhibit absorption in the visible or ultraviolet region when radiation causes an electronic transition within its structure. Thus, the absorption of light by a sample in the ultraviolet or visible region is accompanied by a change in the electronic state of the molecules in the sample. The energy supplied by the light will promote electrons from their ground state orbital to higher energy, excited state orbital or anti-bonding orbital. Potentially, three types of ground state orbitals may be involved [24, 25].

4.2 Fourier-transform infrared (FTIR) Spectroscopy:

Fourier transform infrared (FTIR) spectroscopy is a fast, affordable, non-invasive technique for evaluating the chemical properties of biological samples. This method evaluates how infrared radiation interacts with molecular bonds to offer insights into the biochemical substances present in a sample. In plant tissues, FTIR has been utilized to assess how variations in factors such as nutrient availability, water stress, temperature stress, heavy metals, and disease affect plants [26]. Several spectral areas provide insights into lipids, proteins, and other specific interactions within the fingerprint region, offering details on substances such as polypeptides, polyphenolics, and polysaccharides. The assessment of bonding interactions allows for a semi-quantitative analysis of the presence of molecular functionalities (by comparing spectral regions) and the evaluation of their variation within a sample (by examining the shape of absorption bands). FTIR peaks are comparatively narrow and often correlate with the vibration of a specific chemical bond (or a singular functional group) within the molecule [27, 28]. FTIR necessitates relatively greater sample preparation and lacks the capability for confocal imaging. Additionally, the physical impact of infrared is generated through absorption and primarily affects the dipole and ionic bands like O-H, N-H, and C=O [29].

V. RESULTS

5.1 Analysis of UV-Vis Spectroscopy:

The UV-Vis spectroscopy data indicated the highest absorbance peaks for the plant and soil samples at the specified wavelengths, as illustrated in **Figures 6 and 7**, with the corresponding standard values provided in **Table 4**.

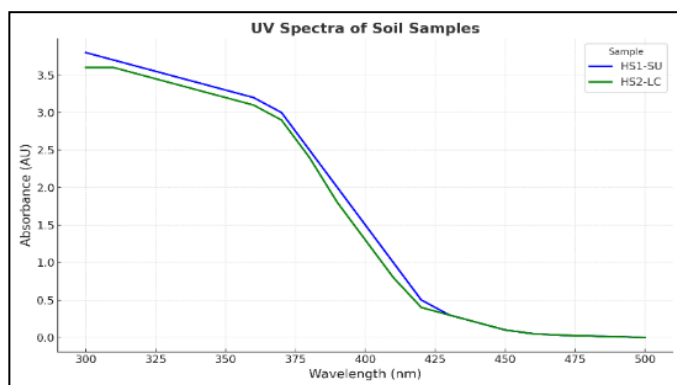


Fig.6: UV-Vis Spectra Analysis of Soil Samples

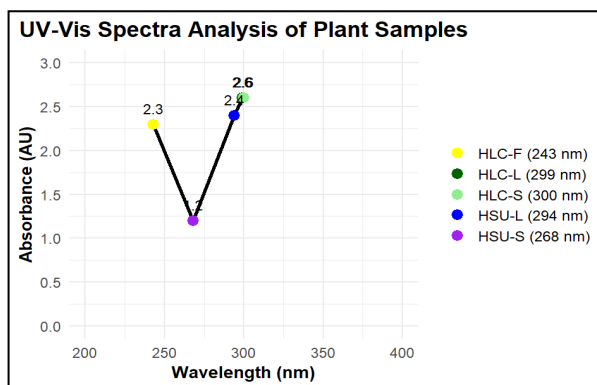


Fig.7: UV-Vis Spectra Analysis of Plant Samples

Evaluation of the UV-Vis Spectroscopy: The graph illustrated the UV-Vis spectral analysis of heavy metal levels in the plant tissue samples of *Lantana camara* and *Senna uniflora*. The absorbance readings at the specified peak wavelengths indicated different degrees of heavy metal accumulation in the samples.

HLC-L (*Lantana camara* leaves, 299 nm, Abs = 2.826): Elevated absorbance reflected strong interaction with the UV-Vis spectrum, implying a greater presence of heavy metals in the leaf tissue of *Lantana camara*. The leaves may have functioned as main accumulators, likely because of direct contact with environmental contaminants.

HLC-S (*Lantana camara* stem, 300 nm, Abs = 2.780): The similar absorbance observed in HLC-L indicated that the stem tissues held a comparable level of heavy metals. This might have been due to the vascular system of the plant moving heavy metals to both its stems and leaves.

HLC-F (*Lantana camara* fruits, 243 nm, Abs = 2.318): Reduced absorbance in comparison to leaves and stems suggested a moderate level of heavy metal accumulation. Flowers may not have gathered heavy metals to the same degree, likely because of physiological differences.

HSU-L (*Senna uniflora* leaves, 294 nm, Abs = 2.231): Moderate absorbance indicated a reduced buildup of heavy metals in *Senna uniflora* leaves when compared to *Lantana camara* leaves. This variation could have resulted from species-specific differences in metal absorption and detoxification processes.

HSU-S (*Senna uniflora* stem, 268 nm, Abs = 1.446): The sample with the lowest absorbance value showed the least heavy metal buildup in the stems of *Senna uniflora*. This indicated that the stem tissue was not as efficient in absorbing heavy metals as other tissues.

Interpretation of the UV-Vis Spectroscopy:

Lantana camara showed a greater capability for heavy metal accumulation in all tissues, positioning it as a more suitable option for phytoremediation purposes. *Senna uniflora*, although able to absorb heavy metals, showed reduced levels of accumulation, indicating that its function may have been better aligned with light remediation or serving as a companion species. The variations in absorbance values revealed species and tissue-specific differences in the mechanisms of heavy metal uptake.

5.2 Analysis of FTIR Spectroscopy:

The FTIR spectra of *Lantana camara* (HS1-LC) and *Senna uniflora* (HS2-SU) plant parts (leaves, roots, stems, and fruits) showed interactions of functional groups that were significant for binding heavy metals. Tables 2 and 3 outlined the maximum absorbance values from the spectra, highlighting potential heavy metal interactions, while Table 4 provided the corresponding standard values for comparison.

Table 2: Peak Absorbance Table (HS1-LC).

Sample	Peak Position (cm ⁻¹)	Functional Group	Potential Heavy Metal Interaction
Leaves	~3420	-OH (hydroxyl)	Chelation, metal binding
	~2925	C-H (alkanes)	Minimal
	~1720	C=O (carboxylic acid/ester)	Chelation, metal complexation
Stem	~1050–1150	C-O (polysaccharides)	Metal adsorption
	~3400	-OH (hydroxyl)	Chelation
	~1620	Amide (C=O stretch)	Protein-metal complex formation
	~1400–1450	Aromatic C-H bending	Possible coordination sites
Fruits	~3400	-OH (hydroxyl)	Weak binding
	~1000–1200	C-O (polysaccharides)	Weak metal adsorption

Evaluation of the FTIR Spectroscopy (HS1-LC):

The FTIR analysis of *Lantana camara* revealed distinct functional groups associated with heavy metal binding. In leaves, peaks at ~3420 cm⁻¹ (-OH stretching), ~2925 cm⁻¹ (C-H stretching), ~1720 cm⁻¹ (C=O stretching), and ~1050–1150 cm⁻¹ (C-O stretching) indicated active sites for chelation, making them a key site for phytoremediation. The stems showed peaks at ~3400 cm⁻¹ (-OH stretching), ~2850–2920 cm⁻¹ (C-H stretching), ~1620 cm⁻¹ (amide C=O stretching), and ~1400–1450 cm⁻¹ (C-H bending in aromatics), suggesting the presence of lignocellulosic compounds and amides that supported metal ion binding, making stems a secondary site for accumulation. In fruits, broad -OH stretching at ~3400 cm⁻¹, weak C=O stretching around ~1650–1700 cm⁻¹, and C-O stretching at ~1000–1200 cm⁻¹ indicated limited active functional groups for heavy metal binding, showing lower potential compared to leaves and stems. The findings were additionally illustrated in **Figure 8**.

Table 3: Peak Absorbance Table (HS2-SU)

Sample	Peak (cm ⁻¹)	Functional Group	Possible Metal Interaction
Leaves	~3380	O-H stretching	Interaction with hydroxyl groups
	~1625	C=O stretching	Complexation with metals (e.g., Pb, Cd)
	~1089	C-O stretching	Metal-ligand interaction (alcohols)
Stem	~3425	O-H stretching	Metal-hydroxyl interaction
	~1654	C=O stretching	Binding to metals (e.g., Cu, Zn)
	~1015	C-O stretching	Polysaccharide-metal interaction
Roots	~3340	O-H stretching	Metal coordination via hydroxyl groups
	~1588	C=O stretching (carboxylate)	Interaction with metals (e.g., Cd, Fe)
	~1060	C-O stretching	Interaction with alcohols/phenols

Evaluation of the FTIR Spectroscopy (HS2-SU):

The FTIR spectra of *Senna uniflora* tissues revealed characteristic peaks that suggested potential sites for metal interaction. The leaves exhibited peaks around 3200-3400 cm^{-1} (O-H stretching), 1600-1700 cm^{-1} (C=O stretching), and 1000-1200 cm^{-1} (C-O stretching), indicating the presence of alcohols or polysaccharides. The stems showed peaks near 3400 cm^{-1} (O-H), 1600 cm^{-1} (C=O), and 1000 cm^{-1} (C-O), highlighting functional groups available for metal binding. The roots displayed significant peaks near 3200-3600 cm^{-1} (O-H stretching), 1400-1700 cm^{-1} (C=O or N-H), and 1000-1200 cm^{-1} (C-O stretching), further confirming their potential role in heavy metal uptake. The findings were additionally illustrated in **Figure 9**.

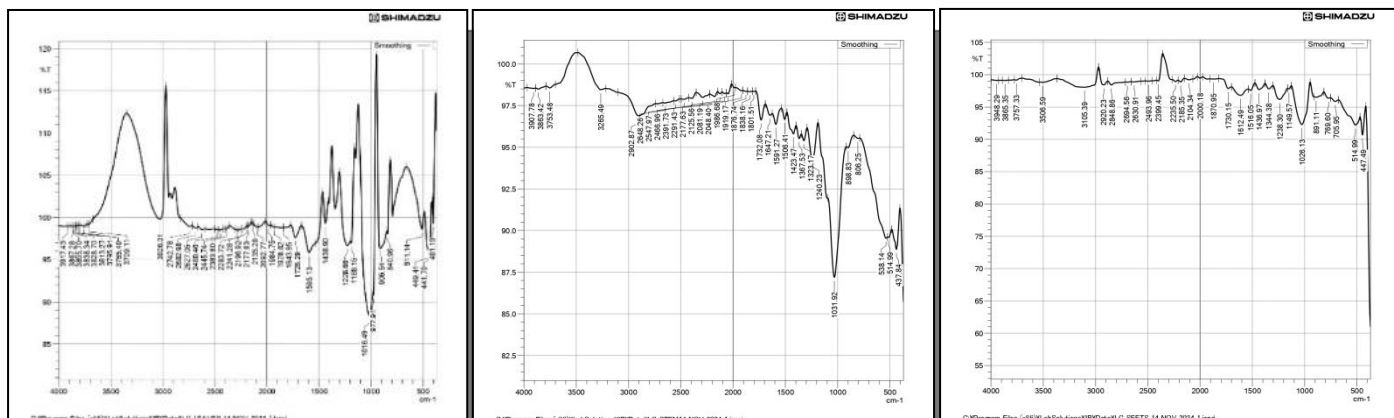


Fig.8: FTIR Analysis of Heavy Metal Interactions in *Lantana camara* (leaves, stems and fruits)

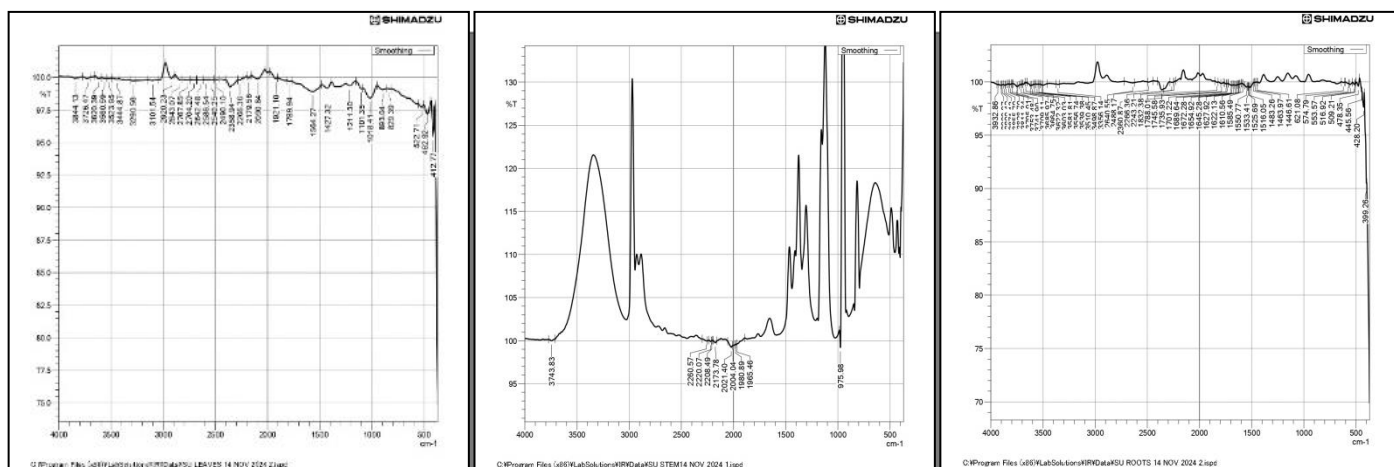


Fig.9: FTIR Analysis of Heavy Metal Interactions in *Senna uniflora* (leaves, stems and roots)

Table 4: Standard Absorption Peaks of Heavy Metals in UV-Vis and FTIR Spectroscopy.

(UV-Vis Spectra) Metals	Standard Absorption Peak(nm)	(FTIR Spectra) Metals	Standard Absorption Peak(cm^{-1})
Cadmium (Cd)	229 nm	Cadmium (Cd)	400-800
Lead (Pb)	283 nm	Lead (Pb)	500-600
Copper (Cu)	324 nm	Copper (Cu)	450-550
Zinc (Zn)	214 nm	Zinc (Zn)	600-800
Mercury (Hg)	254 nm	Mercury (Hg)	850-1000
Nickel (Ni)	232 nm	Nickel (Ni)	900-1000
Chromium (Cr)	358 nm	Chromium (Cr)	500-700
Arsenic (As)	194 nm	Arsenic (As)	750-950

Analysis of Findings:

The FTIR analysis of *Lantana camara* and *Senna uniflora* tissues verified their capacity to bind heavy metals via specific functional groups. Spectral peaks corresponded with standard absorption ranges for Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Nickel (Ni), and Arsenic (As), emphasizing their potential for phytoremediation.

***Lantana camara*:**

- **Leaves:** Highly effective, showing maxima at approximately 3420 cm^{-1} (-OH), around 2925 cm^{-1} (C-H), close to 1720 cm^{-1} (C=O), and between 1050–1150 cm^{-1} (C-O).
- **Stems:** Intermediate binding ability with maxima at approximately ~3400 cm^{-1} (-OH), ~2850–2920 cm^{-1} (C-H), and ~1620 cm^{-1} (amide C=O).
- **Fruits:** Restricted capacity because of a smaller number of active functional groups (~3400 cm^{-1} , ~1650–1700 cm^{-1} , ~1000–1200 cm^{-1}).

***Senna uniflora*:**

- **Leaves:** Exhibits peaks at 3200–3400 cm⁻¹ (-OH), 1600–1700 cm⁻¹ (C=O), and 1000–1200 cm⁻¹ (C-O), suggesting the presence of alcohols or polysaccharides.
- **Stems:** Moderate capability with maxima around ~3400 cm⁻¹ (-OH) and ~1600 cm⁻¹ (C=O).
- **Roots:** Notable absorption capacity with maxima at 3200–3600 cm⁻¹ (-OH), 1400–1700 cm⁻¹ (C=O or N-H), and 1000–1200 cm⁻¹ (C-O).

In general, *Lantana camara* leaves exhibited the greatest efficiency in binding metals, with stems coming next, whereas *Senna uniflora* roots and leaves also displayed significant potential for phytoremediation in areas contaminated by heavy metals.

VI. DISCUSSION

The study demonstrated the potential of *Lantana camara* and *Senna uniflora* for extracting heavy metals from contaminated soil, providing a viable strategy for soil remediation. The plants showed significant accumulation of heavy metals such as Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Nickel (Ni), and Arsenic (As) across various tissues. The findings highlighted that specific plant species could accumulate high levels of heavy metals in their tissues, offering new insights into the phytoremediation potential of these plants. The study emphasized the importance of soil and environmental conditions when selecting plants for remediation.

Phytoremediation reduced the bioavailability of heavy metals in soil, with a notable decrease in metal concentrations, confirming the plants' ability to remove pollutants. This approach addressed the toxicity risks posed by heavy metals to plants, animals, and humans. However, phytoremediation had limitations, such as its slow process, requiring years for significant accumulation and regular harvesting and disposal of plants, which posed logistical challenges. Despite these drawbacks, the study reinforced its potential as an effective method for heavy metal remediation.

VII. CONCLUSION

The examination showed that heavy metals like Copper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Nickel (Ni), and Arsenic (As) were taken up by different plant sections, encompassing leaves, stems, fruits, and roots. *Lantana camara* showed greater capability for binding heavy metals, especially in its leaves, then stems, which makes it a suitable choice for phytoremediation uses. *Senna uniflora* demonstrated a moderate ability to bind, as the roots and leaves played a role in metal absorption. The findings indicated that using both species together could enhance heavy metal extraction in polluted areas, offering a sustainable approach to boost ecological wellbeing and lower risks to human communities.

VIII. ACKNOWLEDGMENT

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REFERENCES

- [1] Hazrat Ali, Ezzat Khan (2013): Phytoremediation of heavy metals —Concepts and applications. - ELSEVIER, Volume 91, Issue 7. DOI : (<https://doi.org/10.1016/j.chemosphere.2013.01.075>).
- [2] Joonki Yoon, Xinde Cao et al. 2006: Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. - ELSEVIER, Volume 368, Issues 2–3. DOI: (<https://doi.org/10.1016/j.scitotenv.2006.01.016>).
- [3] Adriano D. C., (1986): Trace elements in the terrestrial environment. – Springer-Verlag, New York;. Pp, 533. DOI: (<https://doi.org/10.1017/S0376892900035736>).
- [4] Lichtfouse and Eglinton 1995; Sivarajasekar et al. 2008, 2018b; Sivarajasekar and Baskar 2014a, b, c. DOI: ([https://doi.org/10.1016/0146-6380\(95\)00082-8](https://doi.org/10.1016/0146-6380(95)00082-8)).
- [5] Heinaru et al. 2005; Ayoub et al. 2010; Sivarajasekar and Baskar 2015a, b. DOI: (<https://doi.org/10.1016/j.femsec.2004.09.009>).
- [6] Henry J. R. (2000): In An Overview of Phytoremediation of Lead and Mercury. –NNEMS Report. Washington, D.C.; pp, 3-9.
- [7] Garty 2001; Nagajyoti et al. 2010; Tangahu et al. 2011; Jaishankar et al. 2014. DOI: (<https://doi.org/10.1080/20013591099254>).
- [8] Chanfeng Li, Kehai Zhou, et al., 2019: A Review on Heavy Metals Contamination in Soil: Effects, Sources, and Remediation Techniques, An International Journal, Volume 28, Issue 4. DOI: (<https://doi.org/10.1080/15320383.2019.1592108>).
- [9] Sigurdur Greipsson, (2011) Phytoremediation. Nature Education Knowledge 3 (10).
- [10] Mohammad Iqbal Lone, Zhen-li He, et al., 2008: Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives, J Zhejiang Univ Sci B. DOI: ([10.1631/jzus.B0710633](https://doi.org/10.1631/jzus.B0710633)).
- [11] Arjun Kafle, Anil Timilsina, et al., 2022: Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents, ELSEVIER, Volume 8. DOI: (<https://doi.org/10.1016/j.envadv.2022.100203>).
- [12] Neena Priyanka, P. K. Joshi, et al., 2013: A review of Lantana camara studies in India, International Journal of Scientific and Research Publications (IJSRP), Volume 3, Issue 10. DOI: (<http://www.ijsrp.org/research-paper-2013.php?rp=P221825>).
- [13] The Legume Phylogeny Working Group (LPWG) (2017). "A new subfamily classification of the Leguminosae based on a taxonomically comprehensive phylogeny". Taxon. 66 (1): 44–77. DOI: (<https://doi.org/10.12705/661.3>).
- [14] Jump up to: a b Alshehri, Mohammed M.; Quispe, Cristina; Herrera-Bravo, Jesús; Sharifi-Rad, Javad; Tutuncu, Sena; Aydar, Elif Feyza; Topkaya, Cansu; Mertdinc, Zehra; Ozcelik, Beraat; Aital, Mahima; Kumar, N. V. Anil; Lapava, Natallia; Rajkovic, Jovana; Ertani, Andrea; Nicola, Silvana (2022-02-04). "A Review of Recent Studies on the Antioxidant and Anti-Infectious Properties of Senna Plants". Oxidative Medicine and Cellular Longevity.

DOI: (<https://doi.org/10.1155/2022/6025900>).

- [15] Jump up to: a b c d Marazzi, B.; et al. (2006). "Phylogenetic relationships within Senna (Leguminosae, Cassiinae) based on three chloroplast DNA regions: patterns in the evolution of floral symmetry and extrafloral nectaries". *American Journal of Botany*. 93 (2): 288–303. DOI: (<https://doi.org/10.3732/ajb.93.2.288>).
- [16] Randell, B. R. and B. A. Barlow. 1998. Senna. pp 89-138. In: A. S. George (executive editor). *Flora of Australia* volume 12. Australian Government Publishing Service: Canberra, Australia.
- [17] Huxley, A., et al. (1992). *The New Royal Horticultural Society Dictionary of Gardening*. The Macmillan Press, Limited: London. The Stockton Press: New York. ISBN 978-0-333-47494-5 (set).
- [18] "Senna". Australian Biological Resources Study, Department of Agriculture, Water and the Environment: Canberra. Retrieved 3 June 2023.
- [19] Jeanes, Jeff A.; Stajic, Val. "Senna". Royal Botanic Gardens Victoria. Retrieved 3 June 2023.
- [20] Wiecek, Barbara. "Senna". Royal Botanic Garden Sydney. Retrieved 3 June 2023.
- [21] "Senna". Flora of China. Retrieved 3 June 2023.
- [22] Skoog, D.A. Holler, F.J., Nieman, D.A., *Introduction to UV Spectroscopy in, principle of instrumental analysis*, 5th ed., Cole publication, 2004.
- [23] Analytical process of drugs by ultraviolet (UV) spectroscopy – a review R. Gandhimathi, S. Vijay Raj, M.P. Jyothirmaie Department of Pharmaceutical Analysis, SreeVidyanikethan College of Pharmacy, Tirupathi-517102, Andhra Pradesh, India.
- [24] Sharma Y.R. *Ultraviolet and visible spectroscopy in; Elementary Organic spectroscopy*, 1ed., S.Chand & Company Ltd., New Delhi, 2004; 9-60.
- [25] *Basic UV-Vis Theory, Concepts and Applications*, 7-10.
- [26] Skolik P, McAinsh MR, Martin FL. 2019. ATR-FTIR spectroscopy non-destructively detects damage-induced sour rot infection in whole tomato fruit. *Planta* 249, 925-939.
- [27] Kang, G.S., Ko, H.J., and Choi, C.K. (2003) Chemical bond structure of a-C:F films with a low dielectric constant deposited by using CH₄/CF₄ ICPCVD. *Journal of the Korean Physical Society*, 42 (5): 676–681.
- [28] Hofman, M., Pasieczna, S., Wachowski, L., and Ryczkowski, J. (2006) Speciation of functional groups formed on the surface of carbonaceous materials modified by NO. *Journal of Physics IV France*, 137: 287–290.
- [29] Conroy, J., Ryder, A.G., Leger, M.N., Hennessey, K., and Madden, M.G. (2005) Qualitative and quantitative analysis of chlorinated solvents using Raman Spectroscopy and machine learning. *Proceedings of the International Society of Optical Engineers*, 5826: 131–142.