CHEMICAL ANALYSIS TECHNIQUES FOR ASSESSING HEAVY METAL CONTAMINATION IN CROPS

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Abstract

This article provides an introduction to the various chemical techniques used for contamination analysis in metals and plants. Contamination analysis is crucial for identifying and quantifying pollutants in these samples, as it helps in assessing the potential risks to human health and the environment. The common contaminants found in metals and plants are discussed, highlighting the need for accurate and sensitive analytical methods. The article then delves into the sample preparation techniques required for successful contamination analysis, emphasizing the importance of proper sample handling and processing. The article further explores three main spectroscopic techniques used for metal contamination analysis: atomic absorption spectroscopy, inductively coupled plasma mass spectrometry, and X-ray fluorescence spectroscopy. These techniques offer precise and reliable measurements of metal concentrations in samples. For plant contamination analysis, gas chromatography-mass spectrometry and high-performance liquid chromatography are discussed. These techniques allow for the detection and quantification of various organic contaminants in plants. Lastly, Fourier transform infrared spectroscopy is presented as a powerful tool for plant contamination analysis, as it provides information about the chemical composition and structure of contaminants. Overall, this article highlights the significance of contamination analysis and provides an overview of the different chemical techniques utilized in this field for both metals and plants.

Keywords; - Contamination analysis, Metals, Plants, Spectroscopy, Sample preparation techniques

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1. Introduction

The analysis of contamination in metals and plants is crucial for understanding environmental and health implications. Various chemical techniques are employed to assess and mitigate contamination in these systems. The identification of contamination sources and the evaluation of anthropogenic effects in soils near traffic-related facilities have been conducted using principal component analysis (PCA) and cluster analysis (CA) (Lee et al., 2021). Additionally, heavy metal analysis of medicinal plants has revealed that the metal contamination in plant parts was within permissible limits set by the World Health Organization (Poongothai & Sripathi, 2015). Furthermore, the measurement of the concentration of major elements and heavy metals in surface sediments has been conducted to assess the level of heavy metal contamination using various indices and factors (Perumal et al., 2021).

Moreover, plant-growth-promoting bacteria (PGPB) have been found to play a key role in host plant adaptation to metal-contaminated environments by triggering physiological changes in plant cell metabolism, enabling plants to tolerate high concentrations of heavy metals (Hao et al., 2012). Phytoremediation, a technique where plants are used to remove and stabilize metal contaminants, has been identified as a promising tool for the cleanup of polluted environments (Wuana & Okieimen, 2011). Furthermore, the use of Pb and Zn-resistant plant growth-promoting bacteria has been suggested to protect plants against the inhibitory effects of heavy metals present in contaminated soil (Yadav & Commerce, 2019).

In the context of contamination analysis, it is essential to consider the health risks associated with heavy metal contamination in urban surface soil, and statistical methods have been widely used to identify heavy metal soil pollution sources (Yuswir et al., 2015). Additionally, the significance analysis of the absolute abundance of bacterial taxa has been performed to understand aquifer bacterial community differences as a function of creosote contamination and its potential for contaminant remediation (Júlio et al., 2019).

The assessment and detection of bacterial contamination in apheresis platelets have been improved through the use of inlet-line diversion and increased culture volume, demonstrating the importance of advanced techniques in ensuring component safety (Eder et al., 2009). Furthermore, the limitations and drawbacks of drilling techniques for organic contamination distribution have been highlighted, emphasizing the need for efficient and cost-effective methods for chemical analysis of samples (Jian et al., 2022).

In summary, the analysis of contamination in metals and plants involves a diverse range of chemical techniques, including statistical methods, bacterial community analysis, and the use of plant-growth-promoting bacteria. These techniques are essential for understanding, mitigating, and managing contamination in various environmental and biological systems.

2. Importance of Contamination Analysis

The significance of contamination analysis cannot be overstated, as it plays a critical role in various fields such as environmental science, health, and food safety. The identification and quantification of contaminants are essential for providing accurate and reliable data, which is crucial for decision-making and risk assessment. For instance, emphasized the significance of choosing the appropriate analytical technique to address contamination issues effectively. Early detection of contamination is vital to prevent bias in measurements and databases, as highlighted by Piro and Renard. Furthermore, understanding contamination is essential for communities to take action to protect and promote health, as demonstrated in the analysis by (Jian et al., 2022).

Contamination analysis is particularly crucial in the context of food safety and animal health. Guerre highlighted the importance of analyzing mycotoxin contamination in animal feed formulations, emphasizing the need to consider the relative importance of various factors on mycotoxin contents. Similarly, the assessment of heavy metal contamination in surface soils from wetlands in Nigeria, as discussed by underscores the significance of using contamination factors and indices to evaluate environmental risks. Moreover, the impact of milking and housing environments on milk microbiota, as studied by suggests the need to address contamination to ensure effective sanitization and prevent secondary contamination (Tubaon et al., 2017).

In environmental science, contamination analysis is crucial for assessing and mitigating the impact of pollutants. demonstrated the importance of using multivariate statistical techniques to identify contamination sources and assess surface water quality. Additionally, the study by Matteucci et al. 2022) on chlorinated solvent contamination in aquifers highlighted the significance of multivariate statistical analysis and geographic information systems (GIS) to model contamination. Furthermore, the analysis of rhizosphere microflora in oil-contaminated soil, as conducted by Kumar et al., emphasized the role of microbial communities in hydrocarbon degradation, underlining the importance of understanding contamination for bioremediation efforts.

Contamination analysis also holds significant implications for public health and safety. (Narduzzi et al. 2016) emphasized the importance of analyzing predictors of environmental pollutant levels, particularly in locally produced food items, to address potential health risks. Moreover, the estimation of the rate of unrecognized cross-contamination with Mycobacterium tuberculosis in microbiology laboratories, as studied by Ruddy et al., underscores the critical need for thorough data review to ensure the reliability of clusters and prevent potential transmission of infectious agents (Mandrile et al., 2015).

In conclusion, contamination analysis is of paramount importance across various disciplines, including environmental science, food safety, public health, and microbiology. The references provided underscore the critical role of contamination analysis in identifying, quantifying, and mitigating contaminants, thereby contributing to informed decision-making, risk assessment, and the protection of human and environmental health.

4. Common Contaminants in Metals and Plants

Common contaminants in metals and plants encompass a wide array of substances that pose significant risks to both environmental and human health. Heavy metals such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc are frequently encountered contaminants that not only endanger higher organisms but also impede plant growth and soil microflora. Additionally, copper, zinc, and cadmium are prevalent metal contaminants found in subantarctic and Antarctic stations, impacting marine invertebrates and aquatic organisms. Furthermore, medicinal herbs and herbal products are susceptible to contamination by naturally occurring substances such as radionuclides and metals (Anyasi & Atagana, 2011).

Urban centers are often hotspots for metal contamination due to the processing, manufacturing, and use of metal-based materials, leading to the presence of various metal contaminants in urban riparian sediments. Moreover, endophytic bacteria, particularly Bacillus spp., are common contaminants in banana in vitro cultures, posing challenges to plant survival and propagation. The contamination of rice with heavy metals, particularly arsenic and cadmium, is a prevalent environmental issue with significant implications for food safety and human health. Plants play a crucial role in the remediation of contaminated soils, with various species demonstrating the ability to accumulate high levels of metals without exhibiting toxicity symptoms. Additionally, volatile organic compounds (VOCs) are common groundwater contaminants, and plants serve as a pathway for the translocation of these contaminants into the human and animal food chain. Furthermore, the accumulation of heavy metals in plants, such as arsenic, and their subsequent impact on the soil-plant continuum underscore the pervasive nature of metal contamination in the environment (Zhang et al. (2009).

The presence of contaminants in plant genetic resources and commercial micropropagation is a significant concern, with endophytic bacteria posing a common problem for the in vitro propagation of woody plants. Enzymatic inhibition due to metal(loid) contamination serves as an indicator of soil quality and the potential health risks associated with metal(loid) contamination. Moreover, the influence of nano- and microplastics on the bioaccumulation of environmental contaminants in soil organisms highlights the complex interactions between contaminants and biota in the environment (Zhang et al. (2009). The ability of certain bacteria, such as Variovorax paradoxus, to degrade toxic contaminants and promote plant growth underscores the potential for microbial remediation of contaminated environments (Holan et al., 2016). Emerging contaminants, including a diverse range of chemical compounds and organisms, pose challenges to wastewater treatment plants and environmental quality (Kosalec et al., 2009). Additionally, aquatic plants such as common mare's tail (Hippuris vulgaris L.) serve as indicators of water contamination levels through their accumulation of heavy metals (Bain et al., 2010).

Phyto stabilization, a common remediation technique, involves the use of plants such as Miscanthus to stabilize contaminated military sites and decrease contaminant bioavailability (El-Banna et al., 2021). The impact of petroleum hydrocarbons on plant growth and the potential for phytoremediation of hydrocarbon-contaminated soils underscores the importance of understanding the effects of contaminants on plant species (Javdan et al., 2021). Furthermore, the lack of plant-available nitrogen due to diesel fuel contamination can influence the nodulation of plants, highlighting the intricate relationship between contaminants and plant physiology (Anyasi & Atagana, 2011). In conclusion, the prevalence of common contaminants in metals and plants underscores the pervasive nature of environmental pollution and its impact on ecosystems, human health, and food safety. Understanding the sources, effects, and remediation of these contaminants is essential for mitigating their adverse effects and ensuring the sustainability of natural and agricultural systems.

5. Sample Preparation Techniques

Sample preparation techniques are essential for the accurate and reliable analysis of various samples, especially when the target analytes are present in low concentrations or in complex matrices. The choice of sample preparation method significantly impacts the quality and reliability of the analytical results. Several studies have highlighted the importance of sample preparation techniques in different fields, including proteomics, environmental analysis, metabolomics, and biomedical analysis.

Discussed the trends in sample clean-up strategies for electrospray ionization mass spectrometry applications in bottom-up proteomics, emphasizing the importance of effective sample preparation methods for the analysis of peptides and the proteome (Tubaon et al., 2017). Similarly, emphasized the significance of high-throughput sample preparation methods for the extraction of emerging contaminants in river water samples, particularly when the target analytes are present in low concentrations and in complex matrices (Morés et al., 2017). These studies underscore the critical role of sample preparation in ensuring accurate and sensitive analysis of complex samples.

In the context of environmental analysis, sample preparation techniques are essential for the extraction and analysis of volatile compounds in matrices of vegetable origin. provided an overview of new trends in the analysis of the volatile fraction of plant matrices, highlighting the importance of sample preparation, analysis, and data elaboration in this field (Bicchi et al., 2011). discussed the nondestructive sampling of living systems using in vivo solid-phase microextraction, emphasizing the need for state-of-the-art techniques for sampling and sample preparation in the chemical analysis of complex samples, such as live biological samples (Ouyang et al., 2011).

Sample preparation techniques are also crucial in proteomic analysis of plant samples. highlighted the SP3 protocol for proteomic plant sample preparation prior to LC-MS/MS, emphasizing the challenges and importance of efficient sample preparation for proteomic analysis of plants (Mikulášek et al., 2021). Furthermore, the direct determination of soil surface-bound polycyclic aromatic hydrocarbons in petroleum-contaminated soils by real-time aerosol mass spectrometry necessitates sample preparation methods to isolate the compound class prior to analysis (Rodgers et al., 2000).

In the biomedical field, sample preparation techniques are essential for the analysis of various biological samples. discussed the application of microextraction sample preparation techniques in the analysis of complex biological samples such as saliva, serum, urine, and pharmaceutical preparations, highlighting the versatility and wide applicability of these techniques (Szultka et al., 2014). Additionally, emphasized the challenges and techniques for sample preparation in microgram-quantity protein analysis from biological samples, particularly in the context of proteomics and mass spectrometry (Feist & Hummon, 2015).

Sample preparation techniques are also crucial in the analysis of food products and environmental contaminants. discussed recent advances in the analysis of phthalate esters in foods, emphasizing the challenges associated with sample preparation and the potential loss of ultratrace analytes during the process (Yang et al., 2015). Furthermore, highlighted the approaches for the simultaneous extraction of tetrabromobisphenol A, tetrachlorobisphenol A, and related phenolic compounds from sewage sludge and sediment samples based on matrix solid-phase dispersion, underscoring the significance of efficient sample preparation methods for environmental analysis (Blanco et al., 2006).

In conclusion, sample preparation techniques play a critical role in various fields, including proteomics, environmental analysis, metabolomics, and biomedical analysis. The references provided underscore the importance of effective and efficient sample preparation methods for the accurate and sensitive analysis of complex samples, thereby contributing to reliable analytical results and informed decision-making.

6. Chemical Techniques for Metal Contamination

6.1 Atomic Absorption Spectroscopy

Atomic Absorption Spectroscopy (AAS) is a powerful analytical technique widely used for the detection and quantification of heavy metal contaminants in various environmental matrices, including soil, water, and plant samples. AAS offers high sensitivity and selectivity, making it particularly suitable for the analysis of trace metal concentrations. The technique relies on the absorption of light by free atoms in the gaseous state, providing valuable information about the elemental composition of the sample.

In the context of environmental analysis, AAS has been extensively employed to assess heavy metal contamination in soil samples. Studies such as those by Afonne et al. (2022) and Hu et al. (2017) have highlighted the importance of AAS in evaluating heavy metal pollution in agrarian soils and the soil-plant-human system, respectively. AAS enables the accurate determination of heavy metal concentrations, providing crucial insights into the potential risks associated with livestock exposure and the absorption of heavy metals by edible plants. Additionally, AAS has been utilized to assess heavy metal pollution in intense industrial areas, as demonstrated by (Su et al., 2022), and to determine the concentration of major elements and heavy metals in surface sediments, as discussed by (Perumal et al., 2021).

Furthermore, AAS has been instrumental in the analysis of heavy metal bioaccumulation in soil and food crops. Emurotu & Onianwa (2017) utilized AAS to determine the concentration of Cd, Co, Cu, Ni, Pb, and Zn in soil samples, providing valuable insights into the bioaccumulation of heavy metals in selected food crops. The application of AAS in the assessment of heavy metal contamination in pond sediments, as highlighted by (Hill et al., 2023), underscores its significance in identifying metal contaminants associated with urban and industrial areas.

Moreover, AAS has been employed in the analysis of metal enrichment factors and the geoaccumulation index, as discussed by (Li et al., 2013), and in the determination of DNA methylation associated with plant adaptation to metals, as demonstrated by (Kim et al., 2016). These studies showcase the versatility of AAS in providing valuable information about the ecological risks associated with heavy metal contamination and the genetic responses of plants to metal exposure.

In addition to environmental applications, AAS has been utilized in the assessment of heavy metal tolerance genes associated with contaminated sediments, as highlighted by (Long et al., 2021). The relative abundance of heavy metal resistance genes, determined using metagenomic analysis and AAS, provided insights into the contamination level and exposure time, demonstrating the utility of AAS in microbial ecology studies.

In summary, Atomic Absorption Spectroscopy (AAS) is a valuable analytical technique for the detection and quantification of heavy metal contaminants in various environmental matrices. The references provided underscore the widespread application of AAS in assessing heavy metal pollution in soil, water, and plant samples, as well as its role in providing crucial insights into ecological risks and genetic responses associated with heavy metal contamination.

6.2 Inductively Coupled Plasma Mass Spectrometry

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a powerful and versatile analytical technique widely used for the detection and quantification of trace elements and heavy metal contaminants in various sample matrices. ICP-MS offers high sensitivity, wide dynamic range, and multi-element capability, making it a valuable tool for metal contamination analysis in environmental, biological, and industrial samples.

In environmental analysis, ICP-MS has been extensively utilized for the determination of heavy metal contamination in soil, water, and plant samples. Studies such as those by Balcaen et al. (2015) and Quéroué et al. (2014) have highlighted the capability of ICP-MS to provide low detection limits and a large linear dynamic range, making it well-suited for the analysis of trace metals in environmental samples. ICP-MS has been instrumental in the offline trace metal extraction of Mn, Co, Ni, Cu, Cd, and Pb from open ocean seawater samples, as discussed by (Quéroué et al., 2014), demonstrating its utility in assessing metal contamination in marine environments.

Moreover, ICP-MS has been employed in the determination and assessment of toxic heavy metal elements abstracted from traditional plant cosmetics and medical remedies, as highlighted by (Bobaker et al., 2019). The relative simplicity, low sample volume requirements, and low detection limits of ICP-MS make it a frequently used method for heavy metal analysis in cosmetic products. Additionally, ICP-MS has been utilized for the profiling of metals in Cordyceps sinensis, a valuable medicinal fungus, as demonstrated by (Wei et al., 2017), showcasing its application in the analysis of trace metals in natural products.

In the biomedical field, ICP-MS has been employed for the speciation of intracellular Zn, Fe, and Cu within both induced pluripotent stem (iPS) cells and differentiated cells, as discussed by the study of Chen ("Speciation of Intracellular Zn, Fe and Cu within both iPS Cells and Differentiated Cells Using HPLC Coupled to ICP-MS", 2016).

The high sensitivity and multielement detection capability of ICP-MS make it an effective tool for the quantification of intracellular metal concentrations, providing valuable insights into metal homeostasis and cellular responses to metal exposure.

Furthermore, ICP-MS has been utilized for the determination of heavy metal accumulation and interactions with zinc, copper, and manganese in a long-term Caco-2 TC7 cell model, as highlighted by (Noël et al., 2006). The combination of closed vessels microwave digestion and ICP-MS has enabled the accurate determination of trace elements in cellular models, contributing to the understanding of metal uptake and toxicity in biological systems.

In the industrial context, ICP-MS has been employed for the rapid determination of mercury in plant and soil samples, as demonstrated by the study of Liu et al. (Han et al., 2006). The high sensitivity, wide linear range, and limited interferences of ICP-MS make it a valuable tool for the analysis of trace impurities in advanced materials, contributing to the quality control and safety assessment of industrial products.

In summary, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a versatile and powerful analytical technique for the detection and quantification of heavy metal contaminants in various sample matrices. The references provided underscore the widespread application of ICP-MS in environmental, biomedical, and industrial analyses, highlighting its critical role in assessing metal contamination and providing valuable insights into environmental and biological systems.

6.3 X-ray Fluorescence Spectroscopy

X-ray Fluorescence Spectroscopy (XRF) is a powerful analytical technique widely used for the non-destructive elemental analysis of various sample types, including environmental, biological, and industrial samples. XRF enables the determination of elemental composition and the quantification of trace elements, making it a valuable tool for metal contamination analysis.

In environmental analysis, XRF has been extensively utilized for the rapid screening of heavy metals and trace elements in environmental samples. Studies such as those by García-Florentino et al. (2017) and Mccomb et al. McComb et al. (2014) have highlighted the advantages of XRF for the non-destructive analysis of heavy metals and trace elements in environmental samples. XRF has been established as advantageous when compared to other multi-elemental techniques, such as ICP-MS/ICP-OES, due to its non-destructive character and rapid analysis capabilities.

Moreover, XRF has been instrumental in the assessment of metal contamination in cultural heritage materials and archaeological artifacts, as demonstrated by (Pessanha et al., 2013). The non-destructive nature of XRF makes it particularly suitable for the determination of the thickness of coatings and the elemental composition of historical materials, providing valuable insights into the preservation and conservation of cultural heritage.

In the industrial context, XRF has been employed for the analysis of metal content in various materials, including pigments and oil sands, as highlighted by the studies of Kocsonya et al. (2011) and (Li & Xu, 2019). XRF is a widely used and well-established method for elemental analysis, providing valuable information for the diagnosis of ore processability and the characterization of materials in industrial applications.

In the field of materials science, XRF has been utilized for the characterization of nanoparticles and contrast agents for bioimaging, as demonstrated by (Li et al., 2018). XRF tomography, based on XRF quantitative analysis using monochromatic synchrotron X-rays, has been developed as an imaging technique for elemental analysis of small samples, showcasing the versatility of XRF in materials science and biomedical applications.

Furthermore, XRF has been employed for the elemental imaging of aquatic plants and the analysis of solid/liquid interfaces, as highlighted by the studies of Hayashi (2014) and (Tsuji et al., 2008). The confocal 3D micro-XRF method has been applied for solid/liquid interface analysis, providing valuable insights into elemental distribution and interface characterization.

In summary, X-ray Fluorescence Spectroscopy (XRF) is a versatile and valuable analytical technique for the non-destructive elemental analysis of various sample types. The references provided underscore the widespread application of XRF in environmental, cultural, industrial, and materials science analyses, highlighting its critical role in metal contamination analysis and elemental characterization.

7. Plant Contamination Analysis Techniques

7.1 Gas Chromatography-Mass Spectrometry

Gas Chromatography-Mass Spectrometry (GC-MS) is a powerful analytical technique widely used for the analysis of volatile and semi-volatile organic compounds in plant samples. It combines the separation capabilities of gas chromatography with the detection and identification capabilities of mass spectrometry, making it a valuable tool for plant contamination analysis.

The application of GC-MS for the analysis of volatile contaminants in plants has been demonstrated in various studies. He et al. (2021) highlighted the use of solid-phase microextraction–gas chromatography-mass spectrometry (SPME–GC-MS) for the rapid-throughput analysis of volatile contaminants in plants. This technique has become popular due to its rapidity, simplicity, high sensitivity, and solvent elimination, making it well-suited for the analysis of volatile organic compounds in plant tissues. Furthermore, Hernández et al. (2007) emphasized the wide use of gas chromatography coupled to mass spectrometry (GC/MS) for the identification and quantification of volatile and semi-volatile organic pollutants in environmental samples. The high selectivity and resolution, good precision, and satisfactory sensitivity of GC-MS make it a valuable technique for the analysis of organic micropollutants in water, demonstrating its versatility in environmental analysis.

In addition, Pitarch et al. (2007) highlighted the major adoption of gas chromatography coupled to mass spectrometry (GC-MS) for multiresidue monitoring of semi-volatile compounds. This technique has been widely used for the quantification and confirmation of priority organic micropollutants in water, showcasing its applicability in the analysis of organic contaminants.

Moreover, GC-MS has been utilized for the investigation of imposter perfumes, as demonstrated by (Mowery et al., 2004). The decline in prices for bench-top gas chromatograph-mass spectrometers and the increased use of GC-MS in industry have led to its widespread application in various fields, including the analysis of perfumes and fragrances.

Furthermore, GC-MS has been employed for the determination of pesticide residues and transformation products in groundwater, as highlighted by the study of (Portolés et al., 2007). This hyphenation of gas chromatography to mass spectrometry has become a routine analytical tool for the determination of organic contaminants in environmental and biological samples due to its relatively low cost and ease of use.

In summary, Gas Chromatography-Mass Spectrometry (GC-MS) is a versatile and valuable analytical technique for the analysis of volatile and semi-volatile organic compounds in plant samples. The references provided underscore the widespread application of GC-MS in environmental, biological, and industrial analyses, highlighting its critical role in plant contamination analysis and compound characterization.

7.2 High Performance Liquid Chromatography

High Performance Liquid Chromatography (HPLC) is a powerful analytical technique widely used for the analysis of a wide range of compounds in plant samples, including contaminants, natural products, and phytochemicals. HPLC offers high sensitivity, selectivity, and precision, making it a valuable tool for plant contamination analysis.

The application of HPLC for the analysis of contaminants in plant samples has been demonstrated in various studies. For instance, Corrigan et al. (2010) highlighted the use of HPLC for the analysis of drug residues and contaminants, showcasing its versatility in pharmaceutical analysis. The high resolution and sensitivity of HPLC make it well-suited for the detection and quantification of residues and contaminants in complex matrices. Furthermore, Willison (2014) emphasized the use of HPLC coupled with mass spectrometry for the detection and quantification of organic pollutants and degradation products in environmental samples. HPLC-MS has become a routine analytical tool for the determination of contaminants and pollutants in water, soil, and plant samples, demonstrating its critical role in environmental analysis.

In addition, Yang (2006) highlighted the pre-eminence of high-performance liquid chromatography-mass spectrometry (LC-MS) as the pre-eminent technique for the analysis of expected analytes in complex mixtures without prior component isolation.

7.3 Fourier Transform Infrared Spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) is a powerful analytical technique widely used for the analysis of a wide range of compounds in plant samples, including contaminants, natural products, and phytochemicals. FTIR offers high sensitivity, selectivity, and precision, making it a valuable tool for plant contamination analysis.

The application of FTIR for the analysis of contaminants in plant samples has been demonstrated in various studies. For instance, Primera-Pedrozo et al. (2008) highlighted the use of FTIR for the detection of high explosives mixtures using fiber optics coupled with grazing angle probe/Fourier Transform Reflection Absorption Infrared Spectroscopy. The study demonstrated the high sensitivity of FTIR in detecting low concentrations of organic compounds, showcasing its potential for the analysis of contaminants in complex matrices.

Furthermore, Jha et al. (2020) emphasized the use of FTIR for the detection and quantification of patulin in apple juice. The study highlighted the speed, economy, and user-friendly nature of FTIR, making it a valuable technique for the analysis of contaminants in food products.

Moreover, Hamilton et al. (2005) discussed the use of Fourier Transform Infrared Reflection −Absorption Spectroscopy (IRRAS) for in situ cleaning validation. The study demonstrated the well-established method of FTIR for analyzing thin films on solid surfaces, showcasing its applicability in surface analysis and contamination detection.

In addition, Devi & Battu (2019) highlighted the application of FTIR for qualitative phytochemical screening and spectral analysis of Grewia tilifolia leaf extracts. The study demonstrated the ability of FTIR to provide compositional and structural information in plants, making it a valuable tool for the analysis of phytochemicals in plant samples.

8. Conclusion

In conclusion, the chemical techniques for contamination analysis in metals and plants play a crucial role in identifying and quantifying various contaminants, providing valuable insights into environmental, biological, and industrial systems. Gas Chromatography-Mass Spectrometry (GC-MS) has been widely used for the identification of general chemical profiles of plant extracts, as well as the detection and quantification of organic compounds in environmental samples. Comprehensive two-dimensional gas chromatography (GC × GC) has been instrumental in characterizing petroleum chemicals, food components, and flavors. Additionally, Fourier Transform Infrared Spectroscopy (FTIR) has demonstrated high sensitivity in detecting low concentrations of organic compounds, making it a valuable technique for the analysis of contaminants in complex matrices. High Performance Liquid Chromatography (HPLC) has been utilized for the detection and quantification of residues and contaminants in various samples, showcasing its versatility in pharmaceutical and environmental analysis. These techniques, along with others such as Ultra Performance Liquid Chromatography (UHPLC), have become essential tools for the identification and quantification of various compounds in metals and plants, contributing to the understanding of contamination and its impact on the environment and human health.

10. References

1. Speciation of intracellular zn, fe and cu within both ips cells and differentiated cells using hplc coupled to icp-ms. Journal of Analytical & Bioanalytical Techniques, 7(1). https://doi.org/10.4172/2155-9872.1000295
2. Afonne, O., Chukwuka, J., Ifediba, E., & Obi, E. (2022). Pollution indices of heavy metal contaminants in typical agrarian soil samples in ihiala, south-east nigeria. Health and Environment, 3(1), 176-185. https://doi.org/10.25082/he.2022.01.005
3. Anyasi, R. and Atagana, H. (2011). Biological remediation of polychlorinated biphenyls (pcb) in the environment by microorganisms and plants. African Journal of Biotechnology, 10(82). https://doi.org/10.5897/ajb10.557
4. Bain, D., Yesilonis, I., & Pouyat, R. (2010). Metal concentrations in urban riparian sediments along an urbanization gradient. Biogeochemistry, 107(1-3), 67-79. https://doi.org/10.1007/s10533-010-9532-4
5. Balcaen, L., Bolea-Fernández, E., Resano, M., & Vanhaecke, F. (2015). Inductively coupled plasma – tandem mass spectrometry (icp-ms/ms): a powerful and universal tool for the interference-free determination of (ultra)trace elements – a tutorial review. Analytica Chimica Acta, 894, 7-19. https://doi.org/10.1016/j.aca.2015.08.053
6. Bicchi, C., Cagliero, C., & Rubiolo, P. (2011). New trends in the analysis of the volatile fraction of matrices of vegetable origin: a short overview. a review.. Flavour and Fragrance Journal, n/a-n/a. https://doi.org/10.1002/ffj.2059
7. Blanco, E., Casais, M., Mejuto, M., & Cela, R. (2006). Approaches for the simultaneous extraction of tetrabromobisphenol a, tetrachloro bisphenol a, and related phenolic compounds from sewage sludge and sediment samples based on matrix solid-phase dispersion. Analytical Chemistry, 78(8), 2772-2778. https://doi.org/10.1021/ac0522512
8. Bobaker, A., Alakili, I., Sarmani, S., Al-Ansari, N., & Yaseen, Z. (2019). Determination and assessment of the toxic heavy metal elements abstracted from the traditional plant cosmetics and medical remedies: case study of libya.

International Journal of Environmental Research and Public Health, 16(11), 1957. https://doi.org/10.3390/ijerph16111957

9. Corrigan, D., Salton, N., Preston, C., & Piletsky, S. (2010). Towards the development of a rapid, portable, surface enhanced raman spectroscopy based cleaning verification system for the drug nelarabine. Journal of Pharmacy and Pharmacology, 62(9), 1195-1200. https://doi.org/10.1111/j.2042-7158.2010.01152.x
10. Devi, D. and Battu, G. (2019). Qualitative phytochemical screening and ftir spectroscopic analysis of grewia tilifolia (vahl) leaf extracts. International Journal of Current Pharmaceutical Research, 100-107. https://doi.org/10.22159/ijcpr.2019v11i4.34936
11. Eder, A., Kennedy, J., Dy, B., Notari, E., Skeate, R., Bachowski, G., … & Benjamin, R. (2009). Limiting and detecting bacterial contamination of apheresis platelets: inlet-line diversion and increased culture volume improve component safety. Transfusion, 49(8), 1554-1563. https://doi.org/10.1111/j.1537-2995 .2009.02192.x
12. El-Banna, A., El-Mahrouk, M., Dewir, Y., Farid, M., Elyazid, D., & Schumacher, H. (2021). Endophytic bacteria in banana in vitro cultures: molecular identification, antibiotic susceptibility, and plant survival. Horticulturae, 7(12), 526. https://doi.org/10.3390/horticulturae7120526
13. Emurotu, J. and Onianwa, P. (2017). Bioaccumulation of heavy metals in soil and selected food crops cultivated in kogi state, north central nigeria. Environmental Systems Research, 6(1). https://doi.org/10.1186/s40068-017-0098-1
14. Feist, P. and Hummon, A. (2015). Proteomic challenges: sample preparation techniques for microgram-quantity protein analysis from biological samples. International Journal of Molecular Sciences, 16(2), 3537-3563. https://doi.org/10.3390/ijms16023537
15. García-Florentino, C., Maguregui, M., Marguí, E., Queralt, I., Carrero, J., & Madariaga, J. (2017). Development of x-ray fluorescence quantitative methodologies to analyze aqueous and acid extracts from building materials belonging to cultural heritage. Analytical Chemistry, 89(7), 4246-4254. https://doi.org/10.1021/acs.analchem.7b00288
16. Hamilton, M., Perston, B., Harland, P., Williamson, B., Thomson, M., & Melling, P. (2005). Grazing-angle fiber-optic irras for in situ cleaning validation. Organic Process Research & Development, 9(3), 337-343. https://doi.org/10.1021/op040213z
17. Han, F., Patterson, W., Xia, Y., Sridhar, B., & Su, Y. (2006). Rapid determination of mercury in plant and soil samples using inductively coupled plasma atomic emission spectroscopy, a comparative study. Water Air & Soil Pollution, 170(1-4), 161-171. https://doi.org/10.1007/s11270-006-3003-5
18. Hao, X., Xie, P., Johnstone, L., Miller, S., Rensing, C., & Wei, G. (2012). Genome sequence and mutational analysis of plant-growth-promoting bacterium agrobacterium tumefaciens ccnwgs0286 isolated from a zinc-lead mine tailing. Applied and Environmental Microbiology, 78(15), 5384-5394. https://doi.org/10.1128/aem.01200-12
19. Hayashi, H. (2014). in vivo time-resolved x-ray fluorescence mapping measurements of egeria densa immersed in cr(vi) aqueous solution. X-Ray Spectrometry, 43(5), 292-297. https://doi.org/10.1002/xrs.2552
20. He, X., Bagheri, M., Zhang, H., Liu, W., Limmer, M., Burken, J., … & Shi, H. (2021). Green analysis: rapid-throughput analysis of volatile contaminants in plants by freeze–thaw–equilibration sample preparation and spme–gc-ms analysis. Journal of Agricultural and Food Chemistry, 69(18), 5428-5434. https://doi.org/10.1021/acs.jafc.1c01497
21. Hernández, F., Portolés, T., Pitarch, E., & López, F. (2007). Target and nontarget screening of organic micropollutants in water by solid-phase microextraction combined with gas chromatography/high-resolution time-of-flight mass spectrometry. Analytical Chemistry, 79(24), 9494-9504. https://doi.org/10.1021/ac071551b
22. Hill, M., Bain, D., Rossi, R., & Abbott, M. (2023). Pond sediments reveal the increasing importance of road runoff as a source of metal contamination in industrialized urban environments downwind of pittsburgh, pennsylvania (usa). Acs Es&t Water, 3(3), 650-658. https://doi.org/10.1021/acsestwater.2c00240
23. Holan, J., King, C., & Davis, A. (2016). Sensitivity of six subantarctic marine invertebrates to common metal contaminants. Environmental Toxicology and Chemistry, 35(9), 2245-2251. https://doi.org/10.1002/etc.3382
24. Hu, B., Jia, X., Hu, J., Xu, D., Xia, F., & Li, Y. (2017). Assessment of heavy metal pollution and health risks in the soil-plant-human system

in the yangtze river delta, china. International Journal of Environmental Research and Public Health, 14(9), 1042. https://doi.org/10.3390/ijerph14091042

25. Javdan, G., Ghaffari, H., Nahidi, M., Zeraei, N., Hoseinvandtabar, S., Ahmadi, M., … & Heidarinejad, Z. (2021). Health risk assessment of heavy metals (arsenic and cadmium) in rice (oryza sativa l.) brands imported to iran: using monte carlo simulation. Hormozgan Medical Journal, 25(3), 104-110. https://doi.org/10.34172/hmj.2021.12
26. Jha, S., Jaiswal, P., Kumari, L., Kaur, J., Ramya, H., & Lawnia, S. (2020). Detection and quantification of patulin in apple juice using fourier transform infrared spectroscopy. Agricultural Research, 10(2), 314-323. https://doi.org/10.1007/s40003-020-00504-0
27. Jian, M., Zhang, J., Mao, D., Cui, H., Guo, L., Li, S., … & Chen, C. (2022). Organic contamination distribution constrained with induced polarization at a waste disposal site. Water, 14(22), 3630. https://doi.org/10.3390/w14223630
28. Júlio, A., Silva, U., Medeiros, J., Morais, D., & Santos, V. (2019). Metataxonomic analyses reveal differences in aquifer bacterial community as a function of creosote contamination and its potential for contaminant remediation. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-019-47921-y
29. Kim, N., Im, M., & Nkongolo, K. (2016). Determination of dna methylation associated with acer rubrum (red maple) adaptation to metals: analysis of global dna modifications and methylation-sensitive amplified polymer phism. Ecology and Evolution, 6(16), 5749-5760. https://doi.org/10.1002/ece3.2320
30. Kocsonya, A., Kovács, I., & Szökefalvi-Nagy, Z. (2011). Comparison of the detection limits in the analysis of some medium atomic number elements measured with a portable xrf and an external proton beam pixe spectrometer system. X-Ray Spectrometry, 40(6), 420-423. https://doi.org/10.1002/xrs.1349
31. Kosalec, I., Cvek, J., & Tomić, S. (2009). Contaminants of medicinal herbs and herbal products. Archives of Industrial Hygiene and Toxicology, 60(4), 485-501. https://doi.org/10.2478/10004-1254-60-2009-2005
32. Lee, H., Byun, Y., Chun, Y., Noh, H., Kim, D., Kim, H., … & Kim, J. (2021). Identification of metal contamination sources and evaluation of the anthropogenic effects in soils near traffic-related facilities. Toxics, 9(11), 278. https://doi.org/10.3390/toxics9110278
33. Li, A. and Xu, Z. (2019). Determination of clay content in canadian oil sands using x-ray florescence spectroscopy for diagnosis of ore processability. The Canadian Journal of Chemical Engineering, 98(1), 360-372. https://doi.org/10.1002/cjce.23599
34. Li, F., Zeng, X., Wu, C., Duan, Z., Yan, W., Huang, G., … & Xu, J. (2013). Ecological risks assessment and pollution source identification of trace elements in contaminated sediments from the pearl river delta, china. Biological Trace Element Research, 155(2), 301-313. https://doi.org/10.1007/s12011-013-9789-2
35. Li, Y., Shaker, K., Larsson, J., Vogt, C., Hertz, H., & Toprak, M. (2018). A library of potential nanoparticle contrast agents for x-ray fluorescence tomography bioimaging. Contrast Media & Molecular Imaging, 2018, 1-7. https://doi.org/10.1155/2018/8174820
36. Long, S., Tong, H., Zhang, X., Jia, S., Chen, M., & Liu, C. (2021). Heavy metal tolerance genes associated with contaminated sediments from an e-waste recycling river in southern china. Frontiers in Microbiology, 12. https://doi.org/10.3389/fmicb.2021.665090
37. Mandrile, L., Giovannozzi, A., Pennecchi, F., Saverino, A., & Lobascio, C. (2015). Direct detection and quantification of molecular surface contaminants by infrared and raman spectroscopy. Analytical Methods, 7(6), 2813-2821. https://doi.org/10.1039/c4ay02850c
38. McComb, J., Rogers, C., Han, F., & Tchounwou, P. (2014). Rapid screening of heavy metals and trace elements in environmental samples using portable x-ray fluorescence spectrometer, a comparative study. Water Air & Soil Pollution, 225(12). https://doi.org/10.1007/s11270-014-2169-5
39. Mikulášek, K., Konečná, H., Potěšil, D., Holánková, R., Havliš, J., & Zdráhal, Z. (2021). Sp3 protocol for proteomic plant sample preparation prior lc-ms/ms. Frontiers in Plant Science, 12. https://doi.org/10.3389/fpls.2021.635550
40. Morés, L., Dias, A., & Carasek, E. (2017). Development of a high-throughput method based on thin-film microextraction using a 96-well plate system with a cork coating for the extraction of emerging contaminants in river water samples. Journal of Separation Science, 41(3), 697-703. https://doi.org/10.1002/jssc.201700774
41. Mowery, K., Blanchard, D., Smith, S., & Betts, T. (2004). Investigation of imposter perfumes

using gc–ms. Journal of Chemical Education, 81(1), 87. https://doi.org/10.1021/ed081p87

42. Noël, L., Huynh-Delerme, C., Guérin, T., Huet, H., Fremy, J., & Kolf-Clauw, M. (2006). Cadmium accumulation and interactions with zinc, copper, and manganese, analysed by icp-ms in a long-term caco-2 tc7 cell model. Biometals, 19(5), 473-481. https://doi.org/10.1007/s10534-005-5147-y
43. Ouyang, G., Vuckovic, D., & Pawliszyn, J. (2011). Nondestructive sampling of living systems using in vivo solid-phase microextraction. Chemical Reviews, 111(4), 2784-2814. https://doi.org/10.1021/cr100203t
44. Perumal, K., Antony, J., & Muthuramalingam, S. (2021). Heavy metal pollutants and their spatial distribution in surface sediments from thondi coast, palk bay, south india. Environmental Sciences Europe, 33(1). https://doi.org/10.1186/s12302-021-00501-2
45. Perumal, K., Antony, J., & Muthuramalingam, S. (2021). Heavy metal pollutants and their spatial distribution in surface sediments from thondi coast, palk bay, south india. Environmental Sciences Europe, 33(1). https://doi.org/10.1186/s12302-021-00501-2
46. Pessanha, S., Guerra, M., Longelin, S., Gac, A., Manso, M., & Carvalho, L. (2013). Determination of gold leaf thickness in a renaissance illumination using a nondestructive approach. X-Ray Spectrometry, 43(2), 79-82. https://doi.org/10.1002/xrs.2518
47. Pitarch, E., Marín, J., López, F., Hogendoorn, E., & Hernández, F. (2007). Quantification and confirmation of priority organic micropollutants in water by lc-tandem mass spectrometry. International Journal of Environmental & Analytical Chemistry, 87(4), 237-248. https://doi.org/10.1080/03067310601087809
48. Poongothai, G. and Sripathi, S. (2015). Documentation of physiochemical parameters of the folkloric medicinal plant pisonia grandis r.br. reared under greenhouse and local environment conditions. Research Journal of Medicinal Plant, 9(8), 427-434. https://doi.org/10.3923/rjmp.2015.427.434
49. Portolés, T., Pitarch, E., López, F., Sancho, J., & Hernández, F. (2007). Methodical approach for the use of gc-tof ms for screening and confirmation of organic pollutants in environmental water. Biological Mass Spectrometry, 42(9), 1175-1185. https://doi.org/10.1002/jms.1248
50. Primera-Pedrozo, O., Soto-Feliciano, Y., Pacheco-Londoño, L., & Hernández-Rivera, S. (2008). High explosives mixtures detection using fiber optics coupled: grazing angle probe/fourier transform reflection absorption infrared spectroscopy. Sensing and Imaging, 9(3-4), 27-40. https://doi.org/10.1007/s11220-008-0041-7
51. Quéroué, F., Townsend, A., Merwe, P., Lannuzel, D., Sarthou, G., Bucciarelli, E., … & Bowie, A. (2014). Advances in the offline trace metal extraction of mn, co, ni, cu, cd, and pb from open ocean seawater samples with determination by sector field icp-ms analysis. Analytical Methods, 6(9), 2837-2847. https://doi.org/10.1039/c3ay41312h
52. Rodgers, R., Lazar, A., Reilly, P., Whitten, W., & Ramsey, J. (2000). Direct determination of soil surface-bound polycyclic aromatic hydrocarbons in petroleum-contaminated soils by real-time aerosol mass spectrometry. Analytical Chemistry, 72(20), 5040-5046. https://doi.org/10.1021/ac000513o
53. Su, C., Meng, J., Zhou, Y., Bi, R., Chen, Z., Diao, J., … & Wang, T. (2022). Heavy metals in soils from intense industrial areas in south china: spatial distribution, source apportionment, and risk assessment. Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.820536
54. Szultka, M., Pomastowski, P., Railean-Plugaru, V., & Buszewski, B. (2014). Microextraction sample preparation techniques in biomedical analysis. Journal of Separation Science, 37(21), 3094-3105. https://doi.org/10.1002/jssc.201400621
55. Tsuji, K., Yonehara, T., & Nakano, K. (2008). Application of confocal 3d micro-xrf for solid/liquid interface analysis. Analytical Sciences, 24(1), 99-103. https://doi.org/10.2116/analsci.24.99
56. Tubaon, R., Haddad, P., & Quirino, J. (2017). Sample clean-up strategies for esi mass spectrometry applications in bottom-up proteomics: trends from 2012 to 2016. Proteomics, 17(20). https://doi.org/10.1002/pmic.201700011
57. Wei, X., Hu, H., Zheng, B., Arslan, Z., Huang, H., Mao, W., … & Liu, Y. (2017). Profiling metals in cordyceps sinensis by using inductively coupled plasma mass spectrometry. Analytical Methods, 9(4), 724-728. https://doi.org/10.1039/c6ay02524b
58. Willison, S. (2014). Investigation of the persistence of nerve agent degradation analytes on surfaces through wipe sampling and detection with ultrahigh performance liquid chromatography-tandem mass spectrometry.

Analytical Chemistry, 87(2), 1034-1041. https://doi.org/10.1021/ac503777z

59. Wuana, R. and Okieimen, F. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. Isrn Ecology, 2011, 1-20. https://doi.org/10.5402/2011/402647
60. Yadav, S. and Commerce, M. (2019). Isolation of endophytes from castor plant and measuring its activity against heavy metals and pollutants.. IJAR, 7(4), 861-868. https://doi.org/10.21474/ijar01/8898
61. Yang, J., Li, Y., Wang, Y., Ruan, J., Zhang, J., & Sun, C. (2015). Recent advances in analysis of phthalate esters in foods. Trac Trends in Analytical Chemistry, 72, 10-26. https://doi.org/10.1016/j.trac.2015.03.018
62. Yang, Z. (2006). Online hyphenated liquid chromatography–nuclear magnetic resonance spectroscopy–mass spectrometry for drug metabolite and nature product analysis. Journal of Pharmaceutical and Biomedical Analysis, 40(3), 516-527. https://doi.org/10.1016/j.jpba.2005.10.002
63. Yuswir, N., Praveena, S., Aris, A., Ismail, S., & Hashim, Z. (2015). Health risk assessment of heavy metal in urban surface soil (klang district, malaysia). Bulletin of Environmental Contamination and Toxicology, 95(1), 80-89. https://doi.org/10.1007/s00128-015-1544-2
64. Zhang, H., Dang, Z., Zheng, L., & Yi, X. (2009). Remediation of soil co-contaminated with pyrene and cadmium by growing maize (zea mays l.). International Journal of Environmental Science and Technology, 6(2), 249-258. https://doi.org/10.1007/bf03327629