

A look at research on heavy metals and/or metalloids in Colombia

Una mirada a las investigaciones sobre metales pesados y/o metaloides en Colombia

Gilberto Eduardo Marín Pimentel¹ 

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¹ Universidad Nacional de Colombia. Facultad de Ciencias Agropecuarias. Carrera 32 No. 12-00 Vía Candelaria. 766533. Palmira, Valle del Cauca, Colombia.

Correspondence: gemarinp@unal.edu.co

Abstract

Given the importance of natural environment conservation, a literature review was conducted using major academic databases and specialized journals in the agricultural sciences. The review focused on research carried out in Colombia regarding the interaction of heavy metals and/or metalloids with biotic and abiotic factors in Colombian ecosystems. Instrumental techniques, correlation analyses, toxicity, accumulation, bioindication, elimination, migration, phytoremediation, and biomonitoring related to these chemical elements were analyzed. The research presented primarily addresses the interaction of these elements with inert soil fractions, latent risks to human health from exposure to or consumption of food, alterations in plant morphology, and the capacity of some plants to accumulate metals in the same way as animals. The review also examines the movement of these elements through the food chain, the bioindication potential of certain biological species, and their detoxification capacity. The review does not establish clear points of reference for measuring the impact of heavy metal pollution on Colombian ecosystems using indices or indicators applicable to our context. It is important to further research public health issues related to the types of work Colombians perform or the types of food they consume, seeking to measure the degree of incidence of metals in the diseases they suffer.

Keywords: contamination, interaction, health, heavy metal and sensitivity.

Resumen

En función de la importancia que tiene la conservación del medio natural. Se realizó una revisión de literatura en los principales buscadores académicos y revistas especializadas del ámbito científico agropecuario en los últimos años, con relación a las investigaciones realizadas en Colombia, en referencia a la interacción que tiene los metales pesados y/o metaloides en factores bióticos y abióticos de los ecosistemas de Colombia. Son analizadas las técnicas instrumentales, análisis de correlación, toxicidad, acumulación, bioindicación, eliminación, migración, fitoremediación y biomonitoreo relacionadas con estos los elementos químicos. Las investigaciones presentadas se refieren principalmente a la interacción de estos elementos con fracciones inertes del suelo, riesgos latentes a la salud humana por exposición o consumo de alimentos, alteración de la morfología de las plantas y la capacidad de algunas de ellas para acumular metales del mismo modo que los animales, el movimiento que tienen ellos en la cadena alimentaria, así como la aptitud de bioindicación de algunas especies biológicas y su poder de depuración. La revisión no establece

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puntos claros de soporte para medir la afectación de la contaminación, por metales pesados en los ecosistemas colombianos, a través de índices o indicadores aplicados en nuestro contexto. Es importante profundizar las investigaciones en temas relacionados con la salud pública, asociadas al tipo de labor que realizan los colombianos o el tipo de alimentación que consumen, buscado medir el grado de incidencia de los metales en las enfermedades que padecen.

Palabras clave: contaminación, interacción, metal pesado, salud, sensibilidad.

1. Introduction

This document allowed a review to be carried out of the main investigations conducted in Colombia regarding the behavior of heavy metals and/or metalloids in different areas of agricultural and environmental development that are inherent to soil, water, air, plants or animals. The concept of heavy metal refers to a group of elements that potentially cause toxicity problems, including metals and metalloids such as Cd, Pb, Sn, Cu and Zn, of a relatively high mass ($>4.5 \text{ g cm}^{-3}$) (Rodríguez-Eugenio et al., 2019). These elements have the capacity to be toxic at low concentrations, and from the environmental toxicological point of view, heavy metals and metalloids are defined as having a density greater than 5 g cm^{-3} (Ziegler-Rivera et al., 2026). These elements are dangerous pollutants due to their long average lifetimes and because they are not biodegradable, affecting global food safety because it is impossible to guarantee food free of these harmful agents (Perez Mora, 2021). The chemical form of the heavy metal influences its toxicity, distribution, mobility and biological availability, but not on the total concentration of the element (Reyes et al., 2016).

Regarding toxicity, trace amounts of heavy metals and/or metalloids, normally below 10 mg kg^{-1} , are indispensable for life in the case of Zn, Fe, Cu, Co, Mg and Mo, whereas Cr, As, Hg and Cd are toxic even at low concentrations and have no biological functions (Ziegler-Rivera et al., 2026). Likewise, the metals Hg, As, Cd and Pb are elements with a high degree of toxicity with incalculable consequences for health, unlike elements such as Ba, Li, Al and Sn, which have low harmfulness (Filipoiu et al., 2022). Toxicity from heavy metals can be measured in soils and waters through bioassays. In soils, tests related to seed germination-root elongation are carried out, analyzing the phytotoxic effect, whereas in waters it can be done through the decrease in luminescence when aqueous phases are combined with an aquatic bacterium (*Vibrio fischeri*) over time. Meanwhile, in higher organisms the toxicity of these elements is measured by means of a lethal dose that causes the death of 50% of a living population (LD50), normally rats or mice (Pabón Guerrero et al., 2020).

These elements present great difficulty for remediation in nature due to their high persistence and their capacity to deteriorate bodies of water, agricultural crops and the atmosphere, and are also a great threat to the well-being and health of humans and animals (Rodríguez-Eugenio et al., 2019). The study of these elements is of vital importance in different media, due to their high toxicity, high persistence, rapid accumulation in living organisms, and considering that in the short term they are not easily detectable; that is why their toxicity is directly related to their ability to be absorbed by the biotic factor (Prieto-Méndez et al., 2009; Reyes et al., 2016). Heavy metals are harmful to all living beings; they normally enter the human body through ingestion or absorption, accumulate slowly over time, and become harmful at the point when their accumulation rate exceeds their discharge rate (Kamran et al., 2013).

Consequently, due to their high density, these elements are difficult to remove from organisms and the environment; they do not undergo chemical and biological degradation, and can even move across membranes, accumulating in living organisms (Lara-Trejo & Gaytán-Oyarzun, 2025). When these elements accumulate in bone and fatty tissues, which enclose the noble minerals and are gradually released into the body, this can cause various pathologies (Gueerra et al., 2012). Promoting agricultural productivity through the excessive application of chemical products substantially raises the levels of heavy metals in cultivated soils, which is a cause for alarm, because through the food chain it can endanger human health (Kelepertzis, 2014).

In the study conducted by Mahecha Pulido et al. (2017) the purpose was to gather and identify a starting point for research on heavy metals in Colombia, mainly in agricultural activities, and their main findings reflect limited research on topics involving heavy metals in agricultural productivity (crops, soils or inputs); they also identified that the most studied elements in the country follow the sequence $\text{Cd} > \text{Pb} > \text{Hg} > \text{Cr} > \text{Ni} > \text{Cu} = \text{Zn} = \text{As} > \text{Mn} > \text{Fe}$, with Cd, Pb, Hg and Cr standing out as relevant. The study of these chemical elements is of vital importance in relation to the productivity and sustainability of Colombia's resources.

That is why inadequate agricultural practices favor the entry of heavy metals into soils, which represents a risk to people's health and makes a monitoring system necessary on the part of the entities responsible for preventing this impact (García-Céspedes et al., 2016). The purpose of this document is to provide a look at the emphasis of research conducted in Colombia on heavy metals and/or metalloids in different environments that clarify the needs for future studies on this subject. The review does not establish precise tools to help quantify the impact of contamination by metallic elements in Colombia's ecosystems by means of indices or indicators.

2. Materials and Methods

The study corresponds to a systematic documentary review on the emphasis of research on heavy metals in Colombia in different environments, providing an overview of the main interests in this field and some research shortcomings.

2.1. Bibliographic search and exclusion criteria

The review was carried out for Colombia, including scientific and review articles from 1998 to 2025, with the intention of ensuring relevant and up-to-date information. Language was a restricting factor, limited to Spanish and English. The search criterion was "Investigaciones en Colombia sobre metales pesados" and in English "Research on heavy metals in Colombia," consulting especially Colombian journals that had the greatest representation of published research, such as *Acta Agronómica*, *Revista de Ciencias Agrícolas*, *Ciencia y Tecnología Agropecuaria*, *Revista de Investigación Agraria y Ambiental*, *Respuestas*, among others, and relying on the databases ScienceDirect, Scopus, Springer Link, SciELO and Redalyc. The keywords considered for the search were "heavy metals," "metalloids," "Colombia," "contamination," "biotic factor" and "abiotic factor," using the Boolean operator "and" to find more precise information.

Articles dated earlier than the set limit were excluded, as were those that did not meet the objective of the research and those documents for which the full text could not be obtained. Duplicate documents were removed. A detailed analysis of the titles and abstracts was carried out to establish the relevance of the document, which was then confirmed by careful reading of the content. Research conducted outside Colombia was not considered. Under these conditions, 104 preliminary documents were found, eliminating 3 becau-

se they did not correspond to an article but to official information from an entity.

2.2. Inclusion Criteria

The results of the research on heavy metals were grouped into the following eight areas of interest in the study of these elements: speciation, toxicity, accumulation, bioindication, elimination, migration, phytoremediation and biomonitoring, including instrumental techniques. The selected articles were classified into one or several fields depending on the objective of the research. The most relevant information is presented according to the criteria of the author of this document, organized chronologically for each area. The frequency of each item was determined in a total of 50 investigations that met the inclusion criterion, discarding 51 documents. The analysis found 13 chemical elements (Hg, As, Cd, Cr, Ni, Pb, Co, Cu, V, Fe, Zn, Al, Mn) and the biotic factors (human, plant, animal and microorganisms) and abiotic factors (soil, air, water and others).

3. Results

3.1. Characteristics of instrumental techniques applied to determine heavy metals and/or metalloids

In general, the use of a technique to quantify the concentration of heavy metals in the environmental setting will depend, among other factors, on the number of elements to be sampled, the type of analyte, the available human and physical infrastructure, the matrix, and whether the determination is occasional or routine (Amador, 2010). In determining levels of heavy metals and/or metalloids in Colombia, spectrophotometric techniques stand out, as shown in Table 1, with Flame Atomic Absorption Spectrometry [FAAS] being the most common for metals such as Pb, Cd, Mn, Zn, Fe and As. Atomic Absorption Spectroscopy [AAS], Inductively Coupled Plasma Mass Spectrometry [ICP-MS] and Inductively Coupled Plasma Optical Emission Spectrometry [ICP-OES] are the techniques that stand out as the most widely used in the quantification of metals, and they are based on determining the response of atoms to an energy source in a sample, varying from one to another in the number of elements that can be measured at once and in their sensitivity (Ziegler-Rivera et al, 2026).

AAS uses a flame to excite the atoms and determine the amount of light they absorb, limiting the

analysis to a few elements and with limited sensitivity (Ziegler-Rivera et al, 2026). Atomization of the sample is carried out by three different methods: by flame (FAAS), electrochemically (ETAAS), or by means of hydrides or chemical vapors (CVG-AAS) (Pabón Guerrero et al., 2020). Flame atomization has the weakness of having high detection limits, a limited analytical range, quantifying only a single element with a high sample volume, and emitting flammable gases (Wilschefski and Baxter, 2019). The electrochemical form requires efficient optimization of the temperature and suitable chemical modifiers in order to achieve correct results (Pabón Guerrero et al., 2020). The hydride technique for biological samples requires complex acid digestions, needs a high volume of samples, has a limited analytical range, and is ideal for only a limited number of elements (Wilschefski and Baxter, 2019).

To measure mercury, several authors use Cold Vapor Atomic Absorption Spectrophotometry [CV AAS]. This technique is derived from the generation of hydrides or chemical vapors (Pabón Guerrero et al., 2020). It is a method applicable only to the element Hg, since at room temperature it is the metal that has an appreciable vapor pressure (Skoog et al.,

2001). Moreover, compared with other techniques it has a certain advantage because it is very useful due to its great sensitivity, speed, simplicity and relative freedom from interference (Ruiz Chaves, 2016). It is considered the most suitable technique for measuring Hg (Pabón Guerrero et al., 2020). In this regard, Ortiz Villa et al. (2016) quantified the concentration of Hg in pastures treated with biosolids, using atomic absorption spectroscopy with a hydride generator, highlighting the acceptability and safety of the method.

ICP-MS combines a highly sensitive detector with a very hot plasma that has the capacity to measure heavy metals in extremely small amounts, called ultratracess (less than 1 mg kg⁻¹) (Ziegler-Rivera et al, 2026). ICP-MS is a technique that is broad qualitatively due to its multi-elemental composition, and quantitatively considering the concentration and isotopic abundance in different matrices (Mazarakioti et al., 2022). The advantages offered by ICP-MS lie in its great sensitivity and speed in analyzing many elements, which results in the ability to determine magnitudes lower than ppm and the possibility of covering a larger number of elements in few samples in reduced time (Díaz Zamora, 2017). Other advantages of this technique

Table 1. Techniques used to quantify the concentration of heavy metals and/or metalloids in different ecosystems in Colombia.

Instrumental Technique	Element	Authors
Titration with EDTA using murexide as an indicator	Cu, Ni	Estupiñan et al. (1998)
Flame Atomic Absorption Spectroscopy [FAAS]	Cd, Cu, Mn, Zn, Fe, As, Hg, Pb, Cr	Forero Hernández and Ballesteros González (2004); Hernández et al. (2001); Insuasty et al. (2008); Arroyave et al. (2010); Chamorro and Sánchez Andica (2013); Ortega (2014); Vergara Estupiñán and Rodríguez Africano (2015); Zafra Mejía et al. (2013); Ramírez Niño and Navarro Ramírez (2015); Peláez-Peláez et al. (2016)
UV-Visible Spectrometry [UV-Vis] and/or Scanning Electron Microscopy [SEM]	Fe, Cu, Ni, Mn, Al, Zn, Co	Ríos Álzate and Torres Pérez (2009); Doria Argumedo (2017)
Inductively Coupled Plasma Mass Spectrometry [ICP-MS]	Cr, Cu, Ni, Pb, Zn, Cd, As, Ba, Mn	Flores et al. (2009); Sarria Carabalí (2014); Madera-Parra (2014); Zafra Mejía et al. (2013); Cortes (2015)
Differential pulse anodic stripping voltammetry, adapting a sample digestion according to Hülya	Cd, Pb	Madero and Marrugo (2011)
Direct Mercury Analyzer [DMA-80], EPA 7473 method	Hg	Laza-Durante (2025)
Atomic Absorption Spectroscopy [AAS] (type not specified)	Hg, Cr, Pb, Cu, Fe	Ramirez Franco and Enríquez Enríquez (2015), Martínez et al. (2017), Navarro Martinez et al. (2025).
Hydride Generation Atomic Absorption Spectrophotometry [HGAAS]	Cd, Cr, Pb, Hg	Ortiz-Romero et al. (2015); Ortiz Villa et al. (2016)
Cold Vapor Atomic Absorption Spectrophotometry [CV AAS]	Hg	Arroyave et al. (2010); Madero and Marrugo (2011); Doria Mesquidaz (2013); Ortega (2014); Camargo et al. (2015); Racero-Casarrubia (2017); Fuentes Gándara et al. (2018)
Graphite Furnace Atomic Absorption Spectrophotometry [GFAAS]	Pb, Cd Zn, Cu, Cr, Ni, Zn, V	Doria Argumedo (2015); Racero-Casarrubia et al. (2017); Herrera-Herrera et al. (2019); Fuentes Gándara et al. (2018), Rueda-Saa et al. (2025)

relate to simple sample preparation, a high analytical range, and high interference control with high-resolution and tandem mass instruments (triple quadrupole) (Wilschefski & Baxter, 2019). ICP-MS has reasonable economic costs, except for the plasma Ar and sample preparation; in addition, it can quantify individual isotopes of each element, making it possible to carry out isotopic ratio and dilution measurements (Díaz Zamora, 2017).

At present, Graphite Furnace Atomic Absorption Spectrophotometry [GFAAS] is a technique with high sensitivity because the entire sample is atomized in a small volume, achieving a high density of atoms (OMS, 2013). The disadvantages of GFAAS are that acid digestion is required for certain elements, it has a limited analytical range, low sample throughput, and it is a single-element technique (Wilschefski & Baxter, 2019). ICP-OES is, worldwide, one of the most widely used techniques to quantify trace elements in different matrices that frequently require digestion, based on an electrically neutral, high-energy plasma formed by electrons, ions and neutral particles, normally of argon, that accepts energy from a direct-current or high-frequency electromagnetic field, with maximum temperatures of up to 8000 °K (Jiménez Heinert et al., 2020). The disadvantages include high detection limits, high equipment costs, laboratory installation costs, and the need for highly experienced personnel (Wilschefski & Baxter, 2019).

3.2. Speciation

Speciation refers to the way heavy metals occur in the environment, in forms similar to neutral, ionized, or free elements, and it makes it possible to delimit the chemical complexity of a medium (Castañé et al., 2003). In Colombia, the study presented by Forero Hernández and Ballesteros González (2004) shows the effect of adding sludge to the soil and its result on heavy metals, with a representative increase occurring in the fraction of Cd bound to organic matter, corresponding to the exchangeable fractions and that bound to iron-manganese oxides; meanwhile, Cu showed a greater correlation with the iron-manganese oxide fraction, as did Zn, whereas Pb presented a fraction coupled to organic matter, and finally Mn showed the largest exchangeable fraction compared with the other metals.

Likewise, the Cd fraction obtained a higher percentage (14%) of connection with organic matter in relation to the fraction bound to iron and manganese oxides (4%), for treatments that received additions of sludge from the Salitre wastewater treatment plant, which could be interpreted by the great capacity to

form complexes such as phenol and carboxyl groups common in organic matter (Forero Hernández & Ballesteros González, 2004). Likewise, humified organic matter [HOM] is important in the assimilation of Cd from humic acids because they create solid bonds in the phenolic and carboxylic groups (Bravo et al., 2014).

Soils with high concentrations of organic matter fix a greater proportion of Cd (Estévez et al., 2000). This is a worrying situation in areas with soils of high organic matter content, because it increases the possibility of these elements being absorbed by plant species and passing into the trophic chain. The same situation occurs with Pb in the research conducted by Reyes Guzmán & Avendaño Prieto (2012), which highlights the potential risk to human health.

3.3. Toxicity

Heavy metals maintain a close relationship between the environment and man. They occur naturally in many parts of the ecosystem at low concentrations. When this changes, it raises alarm due to their high toxicity. In Colombia, with respect to toxicity, the study conducted by Bonilla and Castillo (1991) is presented, in which it is shown that pH acts as a controller of metals in the soil and plays a role in their availability to plants. According to their results, in three soil orders characteristic of the Valle del Cauca, they show that at pH values close to 6.5, the metals Cd, Cr and Hg bind strongly to the soil exchange complex.

In another study, Reyes Guzmán and Avendaño Prieto (2012) found that 37.5% of the Pb is bound to the soil and 27.2% is readily accessible to plants or bioavailable, in relation to the total found in the soil, trends that are warning signs due to the risk of becoming part of the food chain. In industrial sector activities, there is evidence of risk from exposure to heavy metals, especially lead, in the air during battery production processes (Hernández, 2001).

In the research carried out by Ríos Álzate and Torres Pérez (2009), heavy metal contents were determined qualitatively and quantitatively in reactions of zinc with copper (II) sulfate pentahydrate, finding the presence of Pb and Ni in zinc sulfate residues, which indicates a high hazard for human health as well as for marine fauna and flora. In the analysis carried out by Peláez et al. (2014) regarding the toxicity of the heavy metals Cd and Pb in *Brachiaria arrecta* plants, adverse changes in plant morphoanatomy were quantified, resulting in the suppression of basic functions associated with nutrition, photosynthesis, cell division, among others. In the study of Calao and Marrugo (2015) in La Mojana, a Colombian region,

they point to DNA damage in the inhabitants due to the effect of the metals Hg and Cd, given that these exceeded the permitted blood limits according to the World Health Organization, 2013. In the review carried out by Londoño et al. (2016), the serious effects that heavy metal levels in food and the environment have on both humans and animals are outlined, directly affecting human health and even causing death.

Cortés et al. (2017) evaluated, in two agricultural soils corresponding to the Andisol and Vertisol orders, the toxicity of the metallic elements Ni, Cd, Cu, Pb and Zn by means of bioassays on *Lactuca sativa* and *Vibrio fischeri*, and inferred the capacity of the two soils to inhibit toxicity, which increased over time and is possibly due to the relationship between the different soil components and the metals. Moving to the north of Colombia, Doria Argumedo (2017), in areas near coal mining extraction, evaluated air quality by measuring the concentrations of the heavy metals Cu, Cd, V and Pb, concluding that the atmospheric environment is not contaminated with Pb, but is with the rest of the metals, as is the rainwater, which results in it not meeting local and international quality standards. Regarding the limiting effects from a productive standpoint, it is important to point out the loss of basic functions in *Brachiaria arrecta* plants with additions of Cd and Pb (Peláez et al., 2014). Conversely, Ramirez Pisco et al. (2018) noted that Cd content in the soil favored the growth of leaf area, root and stem biomass, as well as leaf production in black nightshade plants, which opens the discussion on the limiting and harmful factors of this element or its importance in increasing productivity.

3.4. Accumulation

Regarding studies involving the accumulation of heavy metals in biotic or abiotic factors, Madero and Marrugo (2011) show that cattle from the San Jorge-Sinú areas presented low accumulation of toxic metals (Pb and Hg); nevertheless, it is pertinent for different agricultural and health sector organizations to periodically evaluate these elements in order to prevent an increase in concentrations in animal tissues, and likewise to include good livestock practices. In the work carried out by Doria Mesquidaz et al. (2013) with workers from the El Alacrán mine, mercury concentrations were found in urine, a result of the exposure inherent to their gold amalgamation work, which represents a high risk to their health and shows that this metal is readily retained by biological tissues and that its excretion process is very slow, indicating its toxic power and/or bioaccumulation. On the other hand, Camargo et al. (2015) reported values to be considered regar-

ding contamination in soils associated with the use of Hg and linked to areas near mining activity.

In the research carried out by Zafra Mejía et al. (2015), it was noted that Pb and Zn levels in road sediments exceeded the limits established in Colombia based on the values defined for urban soils in Italy and Turkey. Ortiz-Romero et al. (2015), which sought to determine the concentration of the elements Cr, Cd, Pb and Hg in the sediments and waters of the Magdalena River, cite the importance of these elements as a source of information for assessing the condition of the body of water in terms of its quality. The research by Reyes et al. (2016) shows that the concentration of the chemical elements Cd, Hg, Pb and As is present in the milk and meat of bovine species, associated with the consumption of pastures or forage and even water contaminated by these elements.

In the Colombian Middle Magdalena region, Peláez-Peláez et al. (2016) noted a great adaptation of *Brachiaria* pastures, especially *humidicola* and *decumbens*, to soils with high metal content, mainly in their first 5 cm, which shows that these plants, preferentially in their root systems, are potentially bioaccumulators of Cd and Pb. In 2017, Chaparro et al. (2017) estimated Cd concentrations for granulated and powdered table chocolate produced and distributed in the municipality of Chiquinquirá, Boyacá-Colombia, comparatively establishing higher concentrations in the powdered presentation compared with the granulated presentation, and concluding that this metal was not above the recommended tolerable weekly intake limits for this type of food.

The article presented by Doria Argumedo (2017), with seawater adjacent to the beach in Riohacha, La Guajira, found the content of the metals Co, Cu, Zn, Al, Mn, Ni and Fe, indicating that Ni and Zn have values above the limits permitted for marine and estuarine waters; they also highlight that their origin is anthropogenic, mainly due to mining activity and the biogeochemical cycle of the metals. Herrera-Herrera et al. (2019), for Pb, Cd and Zn, found that according to the limits indicated by the Food and Agriculture Organization [FAO], the European Union and Colombia's Ministry of Health and Social Protection, values were below these limits for all species studied, and that there is no relationship between the accumulation of heavy metals and trophic level, probably due to the waters of origin; they also warn about the canning processes that could be causing contamination by these elements.

This same author points to the risk related to the bioaccumulation process of the metals Pb, Cd and Zn in the Barranquilla community and the area's tourist population, when they measured the concentration

of these elements in three highly commercialized fish species, *Prochilodus lineatus*, *Prochilodus reticulatus* and *Pangasianodon hypophthalmus*, as well as in a brand of tuna and one of sardine, showing low risk in the short term but not in the long term, which demonstrates the need to carry out periodic monitoring of these elements to prevent harm to the health of local residents and visitors. For their part, Fuentes Gándara et al. (2018), in the Mallorquín marsh, Atlántico, worked with fish species seeking to define the density of the metals Ni, Pb, Cr, Cu, Zn, Cd and Hg in muscle and liver tissue, concluding worryingly that all the species had accumulated these elements in both tissues. In the reflection carried out by Vargas Licona and Marrugo Negrete (2019), the risk to the Colombian population from fish consumption is presented, based on analyses of metal concentrations in the muscles, and it also emphasizes the need to generate new productive projects that allow for other food sources.

In the flat zone and foothills of the Valle del Cauca, it was found that in soils of the Mollisol, Inceptisol and Vertisol orders, the levels of the heavy metals Hg, Cd, Cr, Ni, Pb and Co and the metalloid As do not exceed the typical ranges for agricultural soils, and there is also a statistical correlation between some of these elements (Rueda-Saa et al., 2025). In the Colombian Caribbean, in the mouth areas of the Sinú and Magdalena rivers, sediments show concentrations of certain metals and/or metalloids (Cd, As, Cr, Cu and Ni) above the reference values of international standards (Navarro Martinez et al., 2025). Regarding cases of lead contamination, Vargas Mendoza et al. (2024) mention that there is an accumulation of lead in various foods such as panela, rice, beef and cow's milk, potatoes, baby food and strawberries in several departments of Colombia, originating from contaminated soils and irrigation waters in areas of high agricultural and industrial production.

3.5. Bioindication

Organisms or biological communities play the role of bioindicators since they have a close relationship with the conditions of the place or environment in which they develop and serve as a certification of a specific area (Ramírez Cardona et al., 2008). These same authors, in Medellín, Colombia, determined the levels of the elements Mg, Cu, Fe and Ca in the air, using the *pseudolichen plant Tillandsia usneoides*, processing the data with Arc View 8.1 software in the Aburrá Valley. In addition to bioindication, this study can be grouped under the biomonitoring category because the values of the analyzed elements are measured

over time. A species that can be used as a bioindicator for mercury is the Nile tilapia; Vergara Estupiñán and Rodríguez Africano (2015) found in their research a highly significant linear relationship between the metal concentration and the standard length of the fish. Regarding the biological sampling site for measuring heavy metal concentration in animals, Tirado Amador et al. (2015) propose that, in order to avoid bias or errors, it is necessary to use different parts of the body to detect the levels of these elements, for example, hair, nails, saliva, urine or blood, because their concentration can vary depending on the habits or environmental exposure of the animals to these substances.

3.6. Elimination

In the removal of copper and nickel, Estupiñán et al. (1998) used natural clinoptilolite zeolite in wastewater from the electroplating industry, revealing great effectiveness in removing these metals, in addition to the low cost of using sodium zeolite. Lora Silva and Bonilla Gutiérrez (2010) showed the effect of applying different doses of CaCO_3 , CaSO_4 , $\text{Ca}(\text{H}_2\text{PO}_4)_2$, FeSO_4 and activated diatomaceous earth on Cd and Cr levels in lettuce and *ryegrass*, finding, from different doses of these compounds, a significant reduction in metal content for both plant species.

The research carried out by Cortes et al. (2015) suggests, in a very general way, the great possibility of remediating soils subjected to heavy metal contamination using humic acids. Beltrán-Pineda and Gómez-Rodríguez (2016) highlight the importance of microorganisms such as fungi and bacteria in bio-remediation processes in different environments, as well as the use of genetic engineering in such processes, along with the use of metal-hyperaccumulating plants and quite promising techniques such as microremediation and phytoremediation. In El Alacrán, Department of Córdoba, in a mining area, Martínez et al. (2017) found that total copper in agricultural soils was above the permitted limit values for all international guidelines, in contrast to mercury levels, which showed contamination, and that the contents of the metals Fe and Cu were controlled by the chemical properties pH, ECEC and OM, for both total and available forms.

3.7. Migration

The availability of heavy metal concentration is mainly linked to the type of cation considered and to the physicochemical properties of the soil under study (Reinaldo et al., 2014), which governs the mobility of the metals in the soil. Research on *Orthents* and

Tropepts soils in Tangua, Nariño, found that total Cd showed low mobility, with more than 94% concentrated in the surface layer, and less than 50% of it became exchangeable in these soils (IGAC, 1989, as cited in Insuasty et al., 2006).

Likewise, Barragan Moreno (2008) found that Cd retention in the soil is directly associated with organic matter content, and this situation favors non-absorption by plants. Insuasty et al. (2008), in soils of Túquerres, Pasto and Guachucal, evaluated the mobility and fixation of total and exchangeable Cd, which did not exceed the limits permitted by FAO and OMS, and they inferred low mobility of this element in the profile. Chamorro and Sánchez Andica (2013) analyzed the adsorption of Pb in soils within the mining-influenced area of the Buenos Aires District, Department of Cauca, finding low retention by the soil compared with the amount of lead leaving the mine. On the other hand, Cortés et al. (2014) found, for the Andisol and Vertisol soil orders as well as for humic acids, a linear adsorption relationship for Cd, Pb, Zn, Ni and Cu based on the doses supplied, and indicated that an optimal fit to the Freundlich isotherm model was obtained.

Physicochemical conditions can influence the presence of heavy metals in Oxisol-order soils, since no values above international reference values were found (Mahecha-Pulido et al., 2015). Regarding this same concept of migration, Cortés et al. (2017) showed that complex-forming mechanisms slow down the mobility of the metallic elements Cd, Pb, Zn, Ni and Cu, as well as their relationship with the increase in soil pH.

3.8. Phytoremediation

Phytoremediation techniques are a very useful alternative for decontaminating soils with heavy metals. The difficulty lies in traditional forms of phytoremediation, which are very costly over large areas because natural hyperaccumulating plants grow slowly; therefore, it would be useful to rely on genetic engineering or the support of chemical products or microbes (Sarwar et al., 2017). In this regard, Flórez Orjuela and Cotes Cuadro (2006) detected the capacity of *Salvinia natans* to absorb lead, copper and cadmium, as well as its feasibility for use in decontaminating water intended for crop irrigation or drinking water supply. Arroyave et al. (2010) analyzed the transfer of Hg and Cd from the soil to *Brachiaria dictyoneura*, finding that it has a tolerance mechanism for Cd and Hg, a useful result as a phytoremediation agent.

In another environmental area, a study evaluating three plant species as phytoremediation agents in

leachate from sanitary landfills confirmed a significant capacity for metal accumulation in the species, though with the caveat of being considered hyperaccumulators, for which the order of performance was *Gynierium sagittatum* > *Heliconia psittacorum* > *Colocasia esculenta* for the metals Hg, Cd, Cr and Pb (Madera-Parra et al., 2014). In the research article by Ramírez Franco and Enríquez Enríquez (2015), a high affinity of lignin for Pb was found, along with appropriate metal adsorption by lignin. For their part, Domínguez et al. (2016), using the aquatic macrophyte water hyacinth (*Eichhornia crassipes*), sought to remove Hg from waters contaminated with industrial waste, finding high efficiency in removing the metal, although these values did not reach the levels permitted under Colombian drinking water regulations, which implies that this plant can be used at an earlier stage and then another technique used to achieve the values established for water quality for human consumption.

The review carried out by Caviedes Rubio et al. (2016), covering 30 very traditional aquatic plant species in the American tropics, reveals extensive research on the species *Eichhornia crassipes*, *Pistia stratiotes* and *Lemna minor*, with their use in wastewater treatment prevailing and showing great versatility and tolerance for metals in water resulting from industrial activity, although there is some limitation in the removal of certain specific metals. Ramírez Pisco et al. (2018) suggest that *Solanum nigrum* is potentially useful in reducing the level of Cd risk in soils with cacao crops. In the study carried out by Ramírez Cardona et al. (2008), a high correlation was found between Cd and the black nightshade plant (*Solanum nigrum* L.), which highlights the importance of this plant species as a phytoextractor of this metal in soils cultivated with cacao, and mentions the advantages of its rapid growth, lower environmental requirements and good adaptive capacity.

3.9. Biomonitoring

The environmental assessment of a territory is naturally determined through the use of bioindicators, which may be animals, plant species or fungi that must, as a general rule, be abundant in the territory, widely dispersed, sedentary, and able to withstand similar amounts of pollutants without suffering lethal effects (Leyte-Vidal et al., 2019). Research on biomonitoring has centered on the work carried out by Ramírez Cardona et al. (2008), who determined concentrations of the metals Mg, Cu, Fe and Ca in the air through the pseudolichen plant *Tillandsia usneoides*, placing it at 20 stations that measure air quality in the city, dis-

tinguishing areas of contamination with the support of Arc View 8.1 software. A situation similar to the previous study also occurs with cattle, since they can also serve as detectors of pollution by high molecular weight chemical elements (Hg, Cu, Cd and Pb) in the production chain (Madero & Marrugo, 2011). Estrada-Guerrero and Soler-Tovar (2014) mention the importance of using birds as indicators of heavy metal contamination in wetlands, since research has focused on using fish in lotic systems.

4. Discussion

The research presented over the last 25 years in Colombia concerning heavy metals or metalloids mainly refers to the accumulation (26%) and toxicity (20%) of these elements in biotic and abiotic media (Figure 1). It also includes the interaction of these elements with inert soil fractions, availability as a function of pH, latent risks to human health from exposure or food consumption, alteration of plant morphology and the capacity of some plants to accumulate metals in the same way as animals, their movement within the food chain, as well as the bioindication capacity of some biological species and their purifying power.

Pb, Cd and Hg stand out as the elements of greatest interest in Colombia, specifically when analyzed in terms of accumulation and toxicity, and to a lesser extent phytoremediation and migration. Cd was analyzed in 32 investigations, Pb in 24 and Hg in 15 (Figure 2). This shows the greatest interest in these elements regarding their accumulation in the ecosys-

tem. It is necessary to point out some key issues that our territory faces in the dynamics of these elements, and it should be noted that in the Colombian Orinoquía the causes and determining factors that condition Hg concentrations in fish are not precisely known, and this fosters a public health problem (Ortega, 2014). In the research carried out by Zafra Mejía et al. (2015), the intention arises to deepen research related to the effect of climate change on the accumulation of heavy metals in urban areas.

The result of this review encompasses various topics of the Colombian natural environment, including different ecosystem elements associated with biotic and abiotic factors in which heavy metals or metalloids are present (Figure 3). Plants, with a frequency of 15 investigations, far exceed the biotic interest compared with animals (5), humans (2) and microorganisms (1), indicating that most of the research does not clearly specify the biotic factor (27). Carrying out further research on heavy-metal-hyperaccumulating plants as well as tolerant microorganisms would make it possible to reduce the adverse impact of these elements (Beltrán-Pineda & Gómez-Rodríguez, 2016).

Soil corresponds to the most researched abiotic factor (21) in most of the areas, followed by other elements including road and river sediments, processed foods, minerals, wastewater, inorganic salts, among others, highlighting the migration and speciation of these metallic elements in the soil. In the study carried out by Ramirez Franco and Enríquez Enríquez (2015), it was not possible to determine precisely whether the soils under study are contaminated with heavy metals, because to date no reference values or

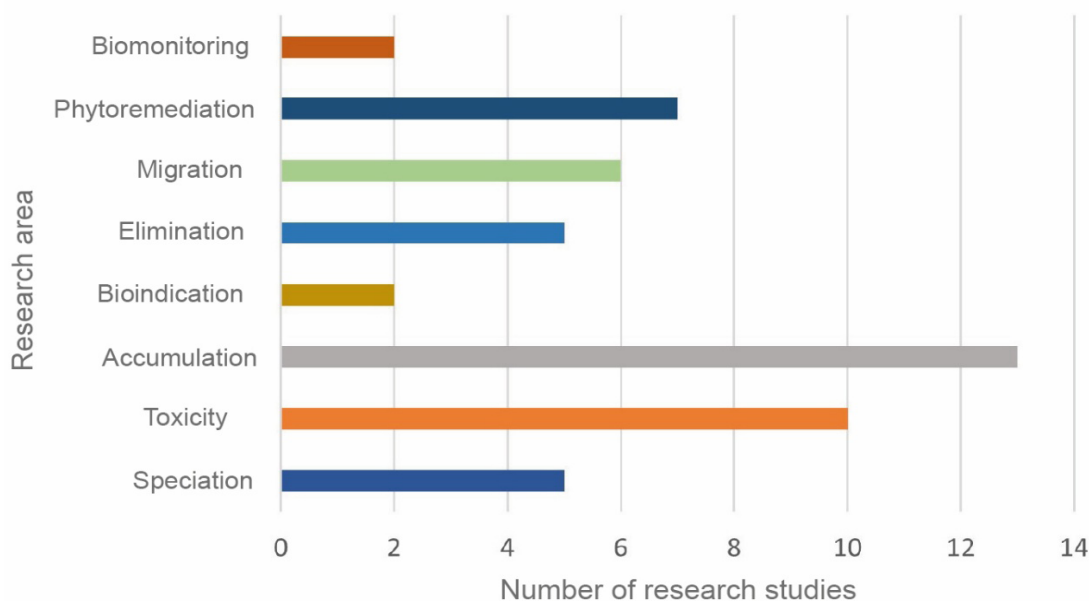


Figure 1. Frequency of research studies in each research area.

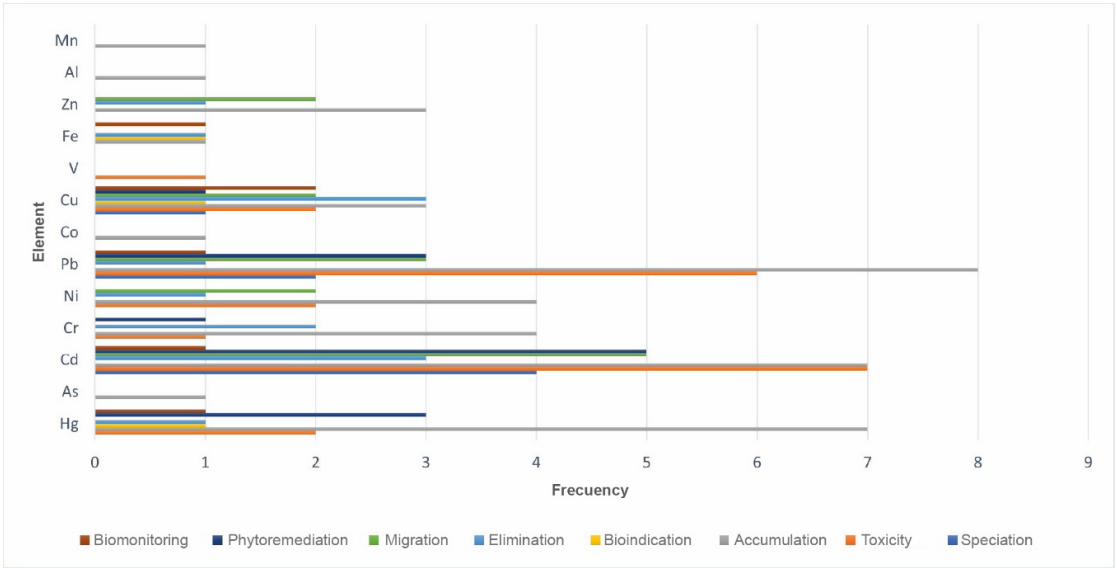


Figure 2. Frequency of the element studied in each research area.

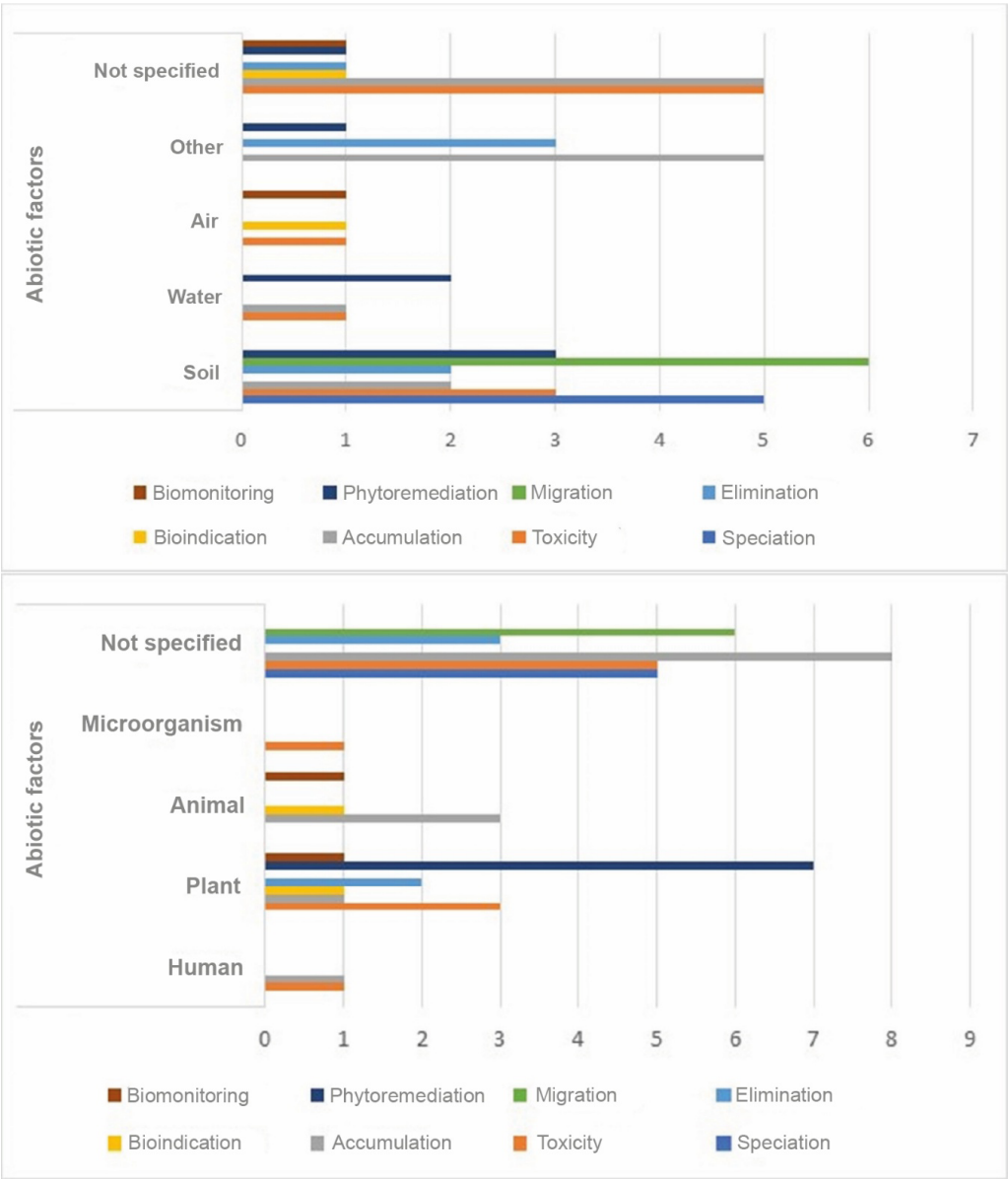


Figure 3. Frequency of the element studied in each research area.

limits associated with the geological formation have been defined, and they indicate the importance of defining these values.

There are several studies related to the accumulation of heavy metals or metalloids in living tissues, and many of them consider reference values for contamination defined in other countries or by international organizations (Zafra Mejía et al., 2013; Herrera-Herrera et al., 2019). In Colombia there is a marked need to define reference values for soil contamination with respect to heavy metal concentration (Rueda-Saa et al., 2011). For example, in the department of Valle del Cauca, Colombia, background and reference values were established for the elements Cd, Cr, Ni, Pb and Co (Marín-Pimentel et al., 2026), with this region being a pioneer in this type of study. Likewise, it would be worthwhile to diversify research by emphasizing the relationship between people's productive activity and their degree of heavy metal poisoning, similar to the study carried out by Rodríguez Heredia (2017), in which a relationship is established between occupation and metal poisoning for certain workers.

This is in consideration of the limited availability of economic resources in the country for environmental research. In this sense, the assessment of metal contamination through bioindication or biomonitoring is a great support for the scientific community. In Colombia, research on this subject includes the work carried out by Ramírez Cardona et al. (2008) using plants and the study with animals by Vergara Estupiñán and Rodríguez Africano (2015), but it is evident that this type of research needs to be increased and the sites with living organisms used for quantification need to be diversified (Tirado Amador et al., 2015), also including non-living ones. At the same time, a useful tool for analyzing the environmental impact of heavy metals and metalloids is the Environmental Impact Assessment (EIA), which makes it possible to quantify, for a specific event, the transfer and accumulation of these elements in ecosystems, because it integrates information on the state of the environment at the time of the study, the event itself, and the weighting of the impact (Sánchez Duarte & Jara Marini, 2017).

Finally, in Colombia there is a need to use different techniques to remediate or remove heavy metals or metalloids in biotic or abiotic environments with the intention of reducing or mitigating the impact on human health. To achieve the removal of heavy metals from the environment, there are physicochemical processes, excavation and landfill disposal, incineration, the use of organic solvents, bioreduction, the use of

chelating agents, bioremediation, tolerance and resistance of microorganisms, hyperaccumulating plants or metallophytes, genetic engineering, among others (Beltrán Pineda & Gómez Rodríguez, 2015). To reduce or remediate the environment, techniques such as chemical immobilization, the use of clean energy, wastewater treatment, limits on industrial emissions, and phytoremediation are used (Ziegler-Rivera et al., 2026). The importance of removing or reducing these elements lies in their toxicity. In organisms, the manifestation of toxicity is associated with the period and level of exposure, the form and specificity of the metal, and the dynamics and kinetics that the element has within the organism, including salinity, pH and temperature as physicochemical factors, and, among biological factors, feeding habits, size, sex, age and the susceptibility of each tissue and/or organism (Sánchez Duarte & Jara Marini, 2017). The main strategy is to prevent the harmful element from reaching the environment; however, the use of plants that absorb and accumulate metals is one of the most widely used techniques. New techniques use improved species or genetic modifications with microbial additions that increase their efficiency, making it possible to recover metals from contaminated soils (Ziegler-Rivera et al., 2026).

5. Conclusions

To quantify heavy metals in Colombia, criteria are needed regarding the importance of each instrumental technique for quantifying heavy metals and/or metalloids and the advantages of using it in different environments. It is important to deepen research on topics related to public health, associated with the type of work Colombians perform or the type of diet they consume, to relate the incidence of metals to the diseases they suffer.

It is necessary to implement regulations that consider permissible limits for heavy metals and metalloids in biotic and abiotic environments that minimize the risk to the environment and public health throughout the territory. Research should be deepened in media such as air and water, including analyses in humans and animals. Analyses of the toxicity and accumulation of these elements in living organisms should continue to be included, based on bioindication or biomonitoring studies. In addition, emphasis should be placed on the study of the elements As, Co, V and Al, without neglecting elements such as Hg, Cd and Pb, which have a high impact on public health.

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Contributor roles

- Gilberto Eduardo Marín Pimentel: conceptualization, investigation, methodology, validation, writing - original draft, writing - review & editing.

Data Availability

The data will be available on request.

Use of Artificial Intelligence

The author declares that no artificial intelligence has been used in the preparation of the manuscript.

Ethical Implications

The author declares that there are no ethical implications.

Conflict of Interest

The author declares that he has no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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