Conciencia Digital

ISSN: 2600-5859
Vol. 8 No. 3, pp. 43 – 61, julio - septiembre 2025
Revista multidisciplinar
Articulo de revisión bibliográfica sistemática..

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Contaminación ambiental debido a la presencia de arsénico en la zona de influencia del volcán Tungurahua. Estudio de caso (ECUADOR)

Evaluation of environmental pollution due to the presence of arsenic in the influence area of the Tungurahua volcano. Case Study (ECUADOR)

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Artículo de Investigación Científica y Tecnológica
Enviado: 14/04/2025
Revisado: 16/05/2025
Aceptado: 30/06/2025
Publicado: 28/07/2025
DOI: **https://doi.org/10.33262/concienciadigital.v8i3.3470**

Cítese: Carrera Beltrán, L. C., Ocaña Coello, S. P., González García, J. C., & León Chimbolema, J. G. (2025). Contaminación ambiental debido a la presencia de arsénico en la zona de influencia del volcán Tungurahua. Estudio de caso (ECUADOR) . *ConcienciaDigital*, *8*(3), 43-62. https://doi.org/10.33262/concienciadigital.v8i3.3470

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La revista es editada por la Editorial Ciencia Digital (Editorial de prestigio registrada en la Cámara Ecuatoriana de Libro con No de Afiliación 663) www.celibro.org.ec

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Palabras claves: Bases de datos; repositorio; ceniza volcánica; erupción volcánica.

Resumen

Introducción: El estudio de la presencia de arsénico en los suelos es de gran importancia debido a sus implicaciones ambientales, agrícolas y sanitarias. **Objetivo:** presentar una revisión bibliográfica de bases de datos sobre las concentraciones de Arsénico (As) a causa de las erupciones volcánicas en la zona de influencia del Volcán Tungurahua (Ecuador). **Método:** se recopiló información en diferentes bases de datos (Scielo, PubMed, WEB OF SCIENCE, ScinceDirect y SCOPUS) y buscadores genéricos (Google Académico). Iniciando con una revisión sobre Arsénico (As), afectaciones a la salud, presencia en ceniza volcánica, estudios en América Latina y Ecuador, y principalmente en la zona de influencia del volcán Tungurahua. **Discusión:** Estudios recientes realizados en Ecuador han identificado concentraciones notables de este metaloide, particularmente en áreas influenciadas por la actividad volcánica. **Conclusiones:** el As es un metal, presente en varios estados de oxidación, forma compuestos orgánicos e inorgánicos. Es un contaminante ambiental hacia los recursos naturales. Se le atribuye enfermedades como cáncer, afecciones pulmonares, entre otras. Pasa al ambiente en forma natural por la quema de carbón o madera, o por erupciones volcánicas. En Ecuador - Provincia de Tungurahua, el volcán con su mismo nombre se mantuvo en erupción por 17 años, la caída de ceniza afectó una amplia zona agrícola-ganadera. Según literatura, se han realizado análisis puntuales de As, encontrándolo en agua, suelo y productos agropecuarios (papas - *Solanum tuberosum*, zanahoria - *Daucus carota*, maíz - *Zea mays*, pastos y leche cruda), por tanto es importante ampliar su estudio en su zona de influencia. **Área de estudio general:** Agropecuaria **Área de estudio específica:** gestión sustentable de los recursos naturales **Tipo de artículo:** revisión bibliográfica sistemática.

Keywords: Scientific databases; volcanic ash; volcanic eruptions.

Abstract

Introduction: The study of arsenic presence in soils is of immense importance due to its environmental, agricultural, and health implications. **Objective:** This review paper is focused on information regarding the presence of arsenic in the influence zone of the Tungurahua volcano (Ecuador) due to volcanic eruptions. **Method:** Information was obtained from various sources such as scientific databases (Scielo, PudMEd, WEB OF SCIENCE, and

Science Direct) and web browsers (Google Scholar). The structure of the review paper is the following: arsenic properties, presence of arsenic in the environment, the impact of arsenic in human health, presence of arsenic in volcanic ash, and a review of research done on arsenic in Latin America mainly in the influence zone of the Tungurahua volcano. **Discussion:** Recent studies conducted in Ecuador have identified notable concentrations of this metalloid, particularly in areas influenced by volcanic activity. **Conclusions:** Arsenic is a toxic metal that produces an impact on the environment and human health. This element is found in several oxidation states and consequently in various organic and inorganic compounds in nature. One of the main sources of arsenic is the ash from volcanoes and specifically in the influence zone of the Tungurahua volcano arsenic has been found in water, soil, raw milk and several agricultural products (potatoes- *Solanum tuberosum*, carrots - *Daucus carota*, corn - *Zea mays*) which implies the need of additional studies in the area. **General area of study:** agriculture Specific **area of study:** sustainable management of natural resources **Type of article:** systematic bibliographic review.

1. Introduction

The study of arsenic presence in soils is important due to its environmental, agricultural, and health implications. Arsenic, one of the most toxic and abundant elements in the Earth's crust, can be present in water, air, and soil, with its inorganic form being the most dangerous to living organisms. In volcanic regions such as the cantons of Mocha, Quero, Cevallos, Pelileo, and especially Penipe, which have been affected by volcanic emissions, natural sources of this element exist, posing a potential contamination risk to agricultural soils and the crops grown there. This contamination becomes a threat to human health, particularly for residents of the area who are exposed to the accumulation of heavy metals through the food chain.

Arsenic (As) is one of the most abundant elements in the Earth's crust, present in trace amounts in rocks, soils, water, and air. In the environment, it is found in its inorganic forms As^{3+} and As^{5+}, with the former being more toxic (Gomez-Caminero et al., 2001; Carbonell-Barrachina et al. 2009; Carbonell et al., 1996). Its toxicity and ability to transform between less and more hazardous species make it a contaminant of environmental, nutritional, and evolutionary concern (Medina-Pizzali et al., 2018;

Conciencia Digital
ISSN: 2600-5859
Vol. 8 No. 3, pp. 43 – 61, julio - septiembre 2025
Revista multidisciplinar
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Velasco, 2018; Fano et al., 2019). In Latin America, volcanic activity represents a significant natural source of arsenic, especially in countries like Ecuador, where volcanic emissions and hydrothermal fluids can contaminate soils and water bodies (Carracedo & Rodríguez, 1993; Neaman et al., 2024).

Additionally, human activities such as metal smelting, pesticide use, and fossil fuel combustion have increased its presence in the environment (Medina-Pizzali et al., 2018). Arsenic has been detected in various foods, including seafood, meats, rice, and algae, indicating its incorporation into the food chain (Gomez-Caminero et al., 2001). Chronic exposure has been linked to multiple diseases, such as skin, lung, bladder, and prostate cancers, as well as genetic alterations, kidney problems, and adverse effects on fetal development (Hall et al., 1999; Secretaría Nacional de Planificación y Desarrollo [SEMPLADES], 2013). In agricultural soils, arsenic dynamics depend on factors such as pH, organic matter, and texture, which influence its absorption by plants and subsequent transfer to humans (Almberg et al., 2017; Turcios, 2010). Therefore, organizations such as the WHO and national regulations like INEN and TULSMA have established maximum permissible limits for arsenic in water, food, and soils to protect public health and the environment (Ecuadorian Institute for Standardization [INEN], 2011; Food and Drug Administration [FDA], 2025; Rodríguez-Eugenio, 2019).

This study aims to evaluate the concentration of arsenic in soils affected by volcanic ashfall, with the goal of generating scientific information that contributes to environmental management, food security, and the protection of public health.

It is important to understand some definitions related to the literature review conducted, to gain a better understanding of arsenic (As) as a chemical element widely distributed in nature, capable of existing in various chemical forms, both organic and inorganic. Its toxicity depends on its oxidation state, origin, and potential risks to human beings. This complex interaction between natural and anthropogenic sources makes arsenic a priority contaminant in environmental and public health studies.

1.1. Arsenic

Arsenic (As) is one of the most abundant elements on earth and it can be found as traces in rocks, soil, water, and air. The oxidation states of arsenic are the following: As^{3-}, As^{0}, As^{3+}, and As^{5+}. However, only As^{3+} and As^{5+} are found in the environment. The main organic compounds containing arsenic are arsenobetaine, salts from trimethylarsine acid, arsenic-containing carbohydrates, and arsenocholine. These types of compounds are less toxic than inorganic compounds and compounds formed with As^{3+} are more toxic than compounds formed with As^{5+}. However, there is the possibility of the conversion from less toxic to more toxic species in nature (Gomez-Caminero et al., 2001). Arsenic has been studied largely as a pollutant in the environment due to its presence at the ecological,

ISSN: **2600-5859**
Vol. 8 No. 3, pp. 43 – 61, julio - septiembre 2025
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nutritional and evolutional levels (Medina-Pizzali et al., 2018; Velasco, 2018; Fano et al., 2019).

1.2. Arsenic in the environment

Geothermal fluids and volcanic emissions are sources of arsenic capable of contaminating soil and water. Since there are many active volcanoes in Latin America, millions of people are threatened by these natural phenomena. Numerous volcanoes, hot springs, geothermal wells, and volcanic fumaroles are found in the Pacific region of Latin America in the countries of Mexico, Guatemala, Honduras, El Salvador Nicaragua, Costa Rica, Ecuador, Bolivia, and Chile. These geothermic systems contain high concentrations of As and other geothermic elements such as Li and B. Concentrations of As >73.6 mg L^{-1} have been found in water with high concentration of NaCl and low concentration of sulfates; the As concentration in water is due to the gases produced in the volcanoes and leachates are produced when volcanic rocks the water (Carracedo & Rodríguez, 1993).

Arsenic concentration in seawater varies from 1-2 µg L^{-1}. However, in the presence of volcanoes or mineral sulfur deposits As concentration has been found to be as high as 12 µg L^{-1}. Meanwhile, in superficial and ground waters As concentration varies from 1-10 µg L^{-1}. On the other hand, arsenic concentration in air is only around 0.02- 4 ng m^{-3} in rural areas. In natural sources of As, concentration can reach up to 12 ng m^{-3} (Gomez-Caminero et al., 2001).

Arsenic and its derivatives are found in the environment due to anthropogenic activities such as the casting of nonferrous metals, the use of fossil fuels and the use of pesticides (Medina-Pizzali et al., 2018). Arsenic has been found in marine organisms and less proportions in terrestrial and freshwater organisms. Food such as seafood, chicken, beef, rice, and seaweed has proven to have high levels of As (Gomez-Caminero et al., 2001). **Table 1** contains information about the types of arsenic compounds found in several types of foods.

Table 1

Main arsenic compounds related to food

Compuesto arsenical	Se encuentra en
Arsenito (As^{+3}) y Arsenato (As^{+5}) [2]	Algas marinas Setas comestibles Vegetales Agua potable Arroz Trigo y productos a base de este Animales de origen marino (en especial bivalvos) Leche y carne y productos a base estos
Ácido monometilarsenoso (MMA^{+3})	Setas comestibles
Ácido dimetilarsinoso (DMA^{+3})	Podría encontrarse en diversos organismos por ser un metabolito inestable de As_{in}
Ácido monometilarsónico (MMA^{+5})	Arroz Setas comestibles Carne de animales [3]
Ácido dimetilarsínico (DMA^{+5})	Arroz Setas comestibles Carne de animales [3]
Arsénico tri-glutation (ATG)	Arroz
Óxido de trimetilarsina (TMAO)	Setas comestibles
Ion Tetrametilarsonio (TMA^{+})	Musculo de animales de origen marino Setas comestibles
Arsenobetaína (AB)	Musculo de animales de origen marino Setas comestibles
Arsenocolina (AC)	Setas comestibles Pescados
Arsenoazúcares	Pescados Algas marinas
Arsenolípidos	Pescados grasos y sus aceites
Ácido 3 –nitro-4 hidroxifenilarsónico (roxarsona)	Carne de aves de corral, en especial pollos
Ácido 4-nitrofenilarsonico (nitrasona)	Carne de aves de corral, es especial pavos

Reference: Medina-Pizzali et al. (2018)

1.3. Arsenic and human health

Arsenic is one of the most toxic elements found in the environment which has negative effects on the ecosystem and human health. Many health problems in pregnant women are associated with the presence of As in countries such as Taiwan, China, India, Argentina, Brazil, Chile, Mexico, among others (Medina-Pizzali et al., 2018; Sánchez, 2017).

Studies performed in drinking water by the application of biomarkers in the exposure to As, genetic susceptibility and gene toxicity in Mexico, Chile, Argentina, Brazil, Colombia, Ecuador and Uruguay between the years of 2011 and 2018 have shown the influence of As in bladder, breast, larynx, prostate, skin and lung cancer. Moreover, As has influenced health problems such as the reduction on cognitive performance, risk factors on the uterus, type 2 diabetes, kidney injuries, lung problems in infants, underweight newborns, low gestational age, anemia, increase on apoptosis, damage to DNA and alteration of genes and proteins (Hall et al., 1999; SEMPLADES, 2013).

1.4. Arsenic in soil

Vegetables contain essential nutrients such as proteins, vitamins, minerals, and fiber. Some of these nutrients are absorbed by plants and their basic composition is made by elements and compounds which can be toxic causing negative effects on the plants. Furthermore, toxins can reach humans through the food chain (Sánchez, 2017).

Minerals in soil have a complex dynamic of absorption and desorption dependent on the type of soil, pH, organic material, humus content, index properties of soil and treatments performed on soils that involve the application of fertilizers and other minerals (Almberg et al., 2017).

The metals in the soil have diverse sources such as fertilizers, atmospheric deposition, volcanic eruptions, and natural erosion of rocks. These metals may be absorbed by plants at high rates which involve a high concentration of metals. Then, the metals may be transferred to herbivorous animals during feeding (Khan et al., 2015).

Heavy metals from the soil, water or air are bio-accumulated in plants through roots or via foliar; plants with big foliar areas and short stems can accumulate a higher concentration of metals. Meanwhile, other plants can resist higher concentrations of metals and chemicals. These capabilities depend on the type and species of the plants (Turcios, 2010).

Contaminated soils are problematic due to their incorporation into agricultural products that can reach humans through diet. Therefore, it is important to consider the maximum content of metals in the soil for agricultural purposes which is 12 mg kg^{-1} (As) (Besoain et al., 1995; Rodríguez-Eugenio, 2019).

1.5. Arsenic regulations

In the 1990s, the World Health Organization reduced the acceptable limits for As in drinking water from 50 µg L^{-1} to 10 µg L^{-1} (Carrión, 2010; Lozano, 2014). Regarding food there are differences such as concentration limits established in the Codex Alimentarius. For example, oils and fats have a limit of 0.1 mg kg^{-1}, mineral water has a limit of 10 µg L^{-1}, milled rice has a limit of 0.2 mg kg^{-1}, and table salt must not have more than 0.5 mg kg^{-1} of As (Food and Drug Administration [FDA], 2025; Jaishankar et al., 2014; Sánchez, 2017; Sanchez, 2018).

In Ecuador INEN establishes the maximum concentration of As in drinking water as 0.01 mg L^{-1}. This regulation is found with the following title: "*Anexo 1. NTE INEN 1108 (2011) sobre agua potable*" (INEN, 2011) about drinking water requirements. Meanwhile, TULSMA in its book VI, annex I published on May 4th, 2015, contains the Standard for Environmental Quality and Effluents Discharge: Resource Water, in which the As concentration limits depend on how water is going to be used. In the same book, annex II, the As concentration limits for soil are established as 12 mg kg^{-1}.

This study was undertaken to provide comprehensive review of the previous studies on the presence of arsenic in soils and agricultural products because of the ash fall due to the eruption of the Tungurahua volcano - Ecuador, and the environmental consequences and the health of the population affected.

2. Methodology

The methodology of this review included defining the topic and establishing the study objectives. Subsequently, the scientific databases to be used were selected, including Scopus, Web of Science, and SciELO. Keywords and Boolean operators for the search were then defined, such as arsenic, volcanic ash, Tungurahua, Latin America. A systematic search was conducted in the selected databases, and the information found was organized using Mendeley. The collected data was then classified, analyzed, and synthesized by considering the key findings of each study and comparing them. The ultimate step was the writing of the article.

3. Discussion

This document addresses the presence of arsenic (As) in Latin America, a subject of increasing scientific interest due to its significant impact on public health and the environment (Bundschuh & Litter, 2010). Recent studies conducted in Ecuador have identified notable concentrations of this metalloid, particularly in areas influenced by volcanic activity (Rodríguez, 2021; Lillo, 2003). One of the most prominent cases is that of the Tungurahua volcano, whose eruptive activity has contributed to the dispersion of arsenic-rich volcanic ash. This phenomenon has raised concerns about the potential contamination of soil, water sources, and agricultural products in surrounding areas, affecting communities that rely directly on these natural resources (Narvaez, 2014). The aim of overarching is to understand the relationship between volcanic activity and arsenic presence to assess environmental risks and inform the development of effective mitigation strategies.

3.1. Research on As in Latin America

Studies performed in countries such as Chile, Mexico, Argentina, Bolivia, Brazil, Colombia, Ecuador, and Uruguay between 2011 and 2018 have found negative effects of As in human health as shown in the As and human health section. Countries in Latin America have many active volcanoes that produce geothermic fluids (water, gas) and together with volcanic rocks contaminate groundwater and soil with moderate to high concentrations of As (Guerrero, 2019). Volcanic ash has also been found to be a source of As in different geographic areas of Latin American countries (Polo, 2009; Bissen &

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ISSN: 2600-5859
Vol. 8 No. 3, pp. 43 – 61, julio - septiembre 2025
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Frimmel, 2003). Levels of As in Latin America have been found to be > 50 µg L^{-1} reaching about 2000 µg L^{-1} which is 200 times higher than the maximum limits established by the World Health Organization (WHO) (Zhao et al., 2009).

In Peru, studies have shown the presence of As in Tumbes River at concentrations of 200 ug kg^{-1}; this river is close to a rice production área (Lin & Puls, 2000). Also in Peru, in the city of Tacna, As has been present in the Sama and Locumba rivers at concentrations higher than 0.01 mg L^{-1} which is the maximum limit allowed. In the same area, the concentration of As was tested in the urine of the adult population; 80.3% of the samples had an As concentration higher than the limits established by the WHO (Ale-Mauricio et al., 2018).

In Chile, there has been gene methylation due to the exposure of newborns and infants to As, lead (Pb), phenols, and phthalates. This exposure has caused several organic diseases and changes in neurological behavior when adulthood is reached (Ale-Mauricio et al., 2018). In Bolivia, the water from Lake Poopó has been found to have a high concentration of inorganic As which is one of the most toxic and carcinogenic elements in nature (Tchernitchin & Gaete, 2018).

3.2. Presence of As in Ecuador

The presence of As in Ecuador is mainly related to hydrothermal processes in volcanic regions such as the Papallacta basin and lagoon, and the Wells of Tumbaco and Guayllabamba (Sánchez, 2017).

Studies performed in various samples of water and soil have shown values of 10 ug L^{-1}, and 4.48 ± 3 mg kg^{-1}, respectively. In rice biomass As concentration has varied depending on the parts of the plant. Rice grains showed values of 0.042-0.125 mg kg^{-1}, leafs showed values of 0.123- 0.286 mg kg^{-1}, and stems showed values of 0.091-0.201 mg kg^{-1} (Gomez-Caminero et al., 2001).

Another study related to As was the “Designing a bacterial biosensor for arsenic detection in water solutions,” this sensor could detect As concentrations between 0.01-0.08 ppm with an error of only 2.8% in comparison with measurements performed by ATOMIC ABSORPTION SPECTROSCOPY (AAS) (Daneshpour et al., 2014).

As has also been found in water at the Biological Reserve of Limoncocha in concentrations of 1 ppb which complies with the Ecuadorian Legislation (0.05 mg L^{-1}). Although, soil and sediments contained As it was concluded that this form of As may have had low solubility in water (Carrión , 2010).

Metals and As were determined in agricultural soils watered with residual water from natural and anthropogenic origins. The geo-accumulation and enrichment factors were

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Vol. 8 No. 3, pp. 43 – 61, julio - septiembre 2025
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determined based on the Cd, Pb, Ni, Cu, Co, Cr, Zn and As contents in Atoyac, Zahuapan, and Alto Balsas rivers, as well as in the Valsequillo Canal (Baque-Mite et al., 2016). Anthropogenic contamination was found in agricultural soils in the Alto Balsas sub-basin (Lozano, 2014).

Arsenic has also been studied in the cities of Cuenca and Azogues. The authors could not find As in the groundwater and drinking water of these two cities. However, many rivers located in this area contained a certain amount of As; the rivers were the following: Tomebamba, Yanuncay, Tarqui, y Machangara (Velasco, 2018).

Arsenic was studied in soils and drinking water in Papallacta parish. The study found out that drinking water contained 11-24 µg L^{-1} of As which is higher than the parameters established by the WHO (10 µg L^{-1}). This high concentration of As may have been related to the presence of thermal springs and diluted volcanic gases. In the case of soils, As concentration was higher than 12 mg kg^{-1} which exceeds the limits established in the Unified Text of the Secondary Legislation of the Environment of Ecuador (Ministerio del Ambiente de Ecuador [MAE], 2015; Besoain et al., 1995). Finally, the sediments of the Papallacta Lagoon had concentrations of As lower than 102 mg kg^{-1} (Jolliffe, 1993), higher than 5.9 mg kg^{-1}, established in the Canadian Council of Ministers of the Environment [CCME], 2001).

Treatment of As has also been studied in Ecuador. One study applied cocoa-bean husk for the adsorption of Sb (III) and As (III); this material was more efficient than other lignocellulosic biomass (Cullen & Reimer, 1989). Another study used nanofiltration with an NF 270 membrane at 90 and 100 psi of pressure to reduce the concentration of As from drinking water. This treatment reduced the As concentration to 0.05 mg L^{-1} which is an acceptable value in the environmental regulations of Ecuador for drinking water (Bissen & Frimmel, 2003).

3.3. Arsenic and volcanic ASH

Volcanic ash is a source of toxic metals for water, especially arsenic (Fano et al., 2019). Arsenic is dispersed naturally in the atmosphere at high temperatures due to the burning of vegetation, burning of fossil fuels and volcanic eruptions; out of all the sources, volcanic eruptions contribute 60% of all the atmospheric flux of As. Arsenic is dispersed in the atmosphere as particulates in the form of trioxide of As. The latter return to the ground by dry or humid deposition (McClintock et al., 2012; Medina-Pizzali et al., 2018).

Using X-Ray Absorption Fine Structure (XAFS) the oxidation state of As and its coordination number has been determined in the volcanic ash of different natures (recent, old, and in loess chacopampeanos sediments). Most of the As had an oxidation state of 5+ in the loess sediments. Meanwhile, in volcanic ash, As has oxidation states of 1- and

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3+. The loess sediments (As^{5+}) could be in the form of arsenates adsorbed in ferric *oxyhydroxides. The ashes from recent eruptions could be associated with arsenic-containing pyrites and there might have been impurities of* As^{3+} in the structure in the form of *oxyhydroxides. In the ashes from old eruption, the dominant oxidation state is 3+ and in lesser quantity* As^{5+} (Khan, et al., 2015; Khan et al., 2020).

3.4. Tungurahua volcano

The Tungurahua volcano has a height of approximately 5023 meters (Briceño et al., 2020), located in the Andes range at 140km south of Quito. The most violent eruption took place in 2006 in which lava columns reached 8km of height and there were huge quantities of hot rocks and ash affecting the cities of Ambato, Pelileo, Cevallos, Quero, Mocha, Tisaleo, Riobamba and Penipe (Hall et al., 1999). The eruption of the volcano destroyed most of the crops of the region and changed the epidemiological map of the population (Guerrero, 2019).

The last eruptive process of the volcano took place from 1999-2014 discharging and depositing almost 0.13km of tephra to the west and southwest of the volcano. Most of the tephra was discharged in the following years: 2001, 2006 and 2014. The Tungurahua volcano is a dangerous geological zone affecting all the cities around it. However, the volcano could work as a natural lab to study the effects of long-lasting eruptions (Bissen & Frimmel, 2003). Based on the mineralogy and size of the ash discharged by the volcano, human health could be severely affected (Coral et al., 2019).

3.5. Contamination by As in the influence zone of the Tungurahua volcano

This section considers research studies on the presence of As in soils, biomass, and agricultural products in the influence zone of the Tungurahua volcano. The studies are scarce and most of them were done 7 years before the end of the eruption process.

Polo (2009) studied the concentration of As in potatoes (Solanum tuberosum), carrots (Daucus carota) and raw milk in zones close to the Tungurahua volcano. The levels of As in this study were below 0.1 mg kg^{-1} which complies with the Codex Standard 193-1995 of Ecuadorian National Institute of Standardization (INEN, 2013), limits for As in food.

Carrión (2010) studied the concentration of As in potatoes (Solanum tuberosum), corn (Zea mays) and raw milk in Guano and Penipe which are cities located in the influence zone of the Tungurahua volcano. The concentrations of As in this study were also below 0.1 mg kg^{-1}, Lozano (2014) studied the concentrations of Cd and As in water sources affected by the volcanic ash of the Tungurahua volcano. It was concluded that the concentrations of these metals were within the acceptable limits established in TULSMA, book VI, and annex I.

4. Conclusions

- Arsenic is considered a toxic metal or metalloid found in nature in organic and inorganic compounds; the latter is more toxic than the former. Arsenic in nature can be found as trivalent and pentavalent. Compounds containing trivalent As are more toxic than compounds containing pentavalent As. However, there is the possibility of the conversion from less toxic to more toxic species in nature.
- Metals such as As, Li, and B can be dispersed naturally in the environment by processes involving elevated temperatures such as hot springs, volcano fumes, geothermic wells, and volcanic eruptions. Latin America is exposed to these metals due to the presence of various volcanoes in the Pacific region.
- Arsenic and its derivatives are found in the environment due to anthropogenic activities such as the casting of nonferrous metals, the use of fossil fuels and the use of pesticides.
- High concentrations of As influence various diseases such as bladder, breast, larynx, prostate, skin, and lung cancer. The reduction in cognitive performance, risk factors on the uterus, type 2 diabetes, kidney injuries, lung problems in infants, underweight newborns, low gestational age, anemia, increase in apoptosis, among others.
- In Latin America, As has been found at high concentrations in soil, water, and agricultural products. The countries with the most scientific production regarding As in different databases are Mexico and Argentina (Science Direct), Bolivia and Brazil (Scielo), Mexico (Web of Science), Mexico and Argentina (Scopus).
- Volcanic ash and the concentration of As in the atmosphere are closely related; the types of arsenic compounds in the environment depend on the time that the eruption process has taken place.
- No information was found in scientific databases about the effects of the eruption process of the Tungurahua volcano in its influence zone; most of the information was taken from undergraduate thesis collection from universities. These studies were only developed in specific places and the effects of As in food (potatoes, carrots, corn, and raw milk) were only studied in Cevallos town.
- The limited information in scientific databases offers an opportunity to study the effects of As in the environment and human population in the influence area of the Tungurahua volcano.

4.1. Acknowledgements

People or institutions that have contributed in some way to research or drafting text, whether through funding, knowledge contribution or research activity.

This research work has been carried out under the project entitled: "Evaluation of bioavailability of heavy metals and their degree of affectation in the areas of influence of the Tungurahua volcano and study of bioaccumulation in soils and products derived from agricultural activities", being carried out under the collaboration of the Grupo Asociado de Investigación en Biotecnología, Ambiente y Química (GAIBAQ) of the Escuela Superior Politécnica de Chimborazo- Ecuador and Grupos de Investigación en Mercados, Calidad y Seguridad Alimentaria (CSA) y el Grupo en Investigación Aplicada en Agroquímica y Medio Ambiente (GIAAMA) de la Universidad Miguel Hernández de Elche-España,, for which the authors are grateful for their funding.

5. Conflict of interest

The authors declare that there is no conflict of interest in relation to the article presented.

6. Authors' Contribution Statement

All authors contributed significantly to the elaboration of the article.

7. Financing costs

This research was funded entirely with the authors' own funds.

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ISSN: **2600-5859**
Vol. 8 No. 3, pp. 43 – 61, julio - septiembre 2025
Revista multidisciplinar
Articulo de revisión bibliográfica sistemática..

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