

## Article

# Potentially Toxic Elements in Local Cigarettes and Marijuana Leaves of Bauchi State, Nigeria: Public Health and Environmental Implications

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## Abstract

Exposure to potentially toxic elements (PTEs) in commonly used substances remains a serious public health concern, especially in low-regulation environments. This study assessed and compared the concentrations of five PTEs, cadmium (Cd), lead (Pb), zinc (Zn), iron (Fe), and copper (Cu), in marijuana and Aspen-brand cigarettes consumed in Bauchi, Nigeria. Using atomic absorption spectrophotometry (AAS), we analyzed PTE content in both substances after acid digestion and proper calibration. Cigarettes showed higher levels of all tested metals. Cd (3.12 µg/g) and Pb (0.88 µg/g) in cigarettes exceeded WHO limits, while marijuana contained lower levels of Cd (0.645 µg/g) and Pb (0.11 µg/g), with only Cd approaching the level that poses environmental and public health concern. Zn (71.2 µg/g), Cu (64.0 µg/g), and Fe (19.2 µg/g) were also significantly higher in cigarettes ( $p < 0.01$ ). The high levels of Cd and Pb in cigarettes indicate that smokers are more exposed to harmful PTEs through inhalation than marijuana users, which points to a greater health risk from cigarette use. These findings call for stronger policies and regulations that ensure cleaner agricultural practices and industrial accountability to minimize exposure to harmful PTEs and protect community health in Bauchi.

**Keywords:** potentially toxic elements; marijuana; cigarettes; contamination; public health

## 1. Introduction

In Nigeria's northeastern region lies Bauchi State, a rapidly urbanizing area where traditional practices, economic hardship, and a growing informal sector converge to shape its environmental and public health landscape. Among these practices is the widespread consumption of cigarettes and marijuana, two substances commonly smoked in the region for recreational and socio-cultural purposes [1]. While the health risks of tobacco and marijuana use have been extensively studied, a less-explored dimension is the contamination of these substances with potentially toxic elements (PTEs). PTEs are natural constituents of the Earth's crust, but human activities such as industrialization, mining, and agricultural practices have drastically increased their prevalence in the environment [2]. Unlike organic pollutants, PTEs do not degrade over time; they persist, accumulate, and infiltrate the food chain, soil, water, and air [3]. The toxic effects of PTEs such as cadmium (Cd), copper (Cu), zinc (Zn), iron (Fe), and lead (Pb) on human health are profound, ranging from organ damage to cancer, neurological disorders, and developmental deficits [3,4]. In Bauchi State, where agricultural and industrial activities coexist with informal waste disposal and mining, the risk of PTEs contamination in consumable products, like cigarettes and marijuana, poses an escalating public health challenge. Smoking, a primary route of exposure, directly introduces these metals into the lungs, bloodstream, and organs, thus amplifying their toxic effects [5]. Understanding the concentrations of PTEs in these substances is critical for safeguarding consumers' health and mitigating environmental risks.

PTEs enter the environment through both natural and anthropogenic pathways. Cd, for example, is released during mining, waste incineration, and the use of phosphate fertilizers, while Pb contamination stems from vehicle emissions, Pb-based paints, and industrial discharges [6,7]. Cu and Zn, though essential micronutrients, are byproducts of mining, smelting, and metal plating industries—their accumulation in soil and crops can reach toxic levels [8]. In the context of marijuana and cigarettes, contamination by PTEs can arise during cultivation, processing, or packaging. Plants grown in contaminated soils absorb PTEs through their roots, accumulating in their leaves and other tissues [9–11]. For instance, Cd—a known carcinogen—is readily taken up by plants from soil, particularly in areas with industrial or agricultural runoff [9]. Pb, another toxic metal, can settle on plant surfaces through airborne particles from industrial emissions or vehicular traffic [12]. Cigarette manufacturing also contributes to contamination, as tobacco leaves may absorb PTEs during cultivation or processing. Additionally, filters and paper used in cigarette production can introduce trace amounts of metals like Cu and Zn [13,14]. Marijuana, often grown informally without regulatory oversight, is similarly susceptible to contamination, especially when cultivated in urban areas with high levels of environmental pollution.

Besides their toxicity and bioaccumulation tendency, PTEs raise concerns for animal health and ecosystems. These metals pollute soil, water, and air when released through mining, industrial activities, agriculture, and improper waste disposal. In soils, PTEs like lead (Pb), mercury (Hg), and cadmium (Cd) harm microbial communities by decreasing microbial biomass and inhibiting key enzymatic processes involved in organic matter decomposition and nutrient mineralization [15]. This disruption hinders crucial microbial functions such as nitrogen fixation and phosphorus cycling, resulting in decreased soil fertility instead of enrichment. Soils affected by this often have reduced nutrient availability, poor structure, and lower productivity, ultimately harming plant growth and ecosystem stability [16]. Endocrine, neurological, and reproductive damage can also occur in terrestrial animals; prey birds are predominantly vulnerable to Pb poisoning. Fish frequently show alterations in their gills, liver, and blood parameters because of metal accumulation in aquatic systems, which can lead to oxidative stress, DNA damage, and organ toxicity [17]. Metal concentrations increase along the food chain through biomagnification, exposing

apex predators, including humans, to dangerously high levels. For example, predatory fish have far greater amounts of Hg [18]. To mitigate these effects, stricter pollution restrictions, environmental monitoring, and greater public knowledge are necessary to address these effects.

PTEs present risks to human health due to their ability to accumulate in the body over time. Each PTE exhibits a unique toxicological profile. Cd, for instance, is classified as a Group 1 carcinogen (carcinogenic to humans), while inorganic Pb compounds, such as Pb oxides and salts, are classified as Group 2A (probably carcinogenic to humans) by the International Agency for Research on Cancer (IARC) [19]. PTEs primarily enter the body through inhalation, dermal, and ingestion. Chronic exposure is linked to kidney dysfunction, bone demineralization, and respiratory diseases [19]. Cd also has long-term effects on cardiovascular health and contributes to oxidative stress at the cellular level [20]. Pb exposure affects nearly every organ in the body, but its neurotoxic effects are particularly severe. Inhalation of Pb from cigarette smoke or contaminated marijuana can result in elevated blood Pb levels, impairing cognitive function, reducing intelligence quotient (IQ), and causing behavioral disorders [21]. In adults, Pb is associated with hypertension, kidney damage, and reproductive issues, including infertility and miscarriage [22].

On the other hand, Cu, though an essential nutrient involved in enzymatic functions and iron metabolism, excessive Cu intake can lead to gastrointestinal distress, liver damage, and oxidative stress [23]. Hence, inhalation of Cu particles during smoking poses additional risks, including respiratory irritation and systemic toxicity. Zn is another essential trace element required for immune function and cellular repair [24]. However, chronic exposure to elevated Zn levels disrupts homeostasis, leading to nausea, immune suppression, and interference with the absorption of other essential minerals such as Fe and Cu [24]. While Fe is vital for oxygen transport and energy production, excessive levels can result in oxidative damage, tissue inflammation, and organ dysfunction [25]. Smoking substances contaminated with Fe exposes the respiratory system to oxidative stress, exacerbating conditions such as chronic obstructive pulmonary disease (COPD) [25].

### 1.1. Global Burden of PTEs

PTE contamination represents a serious threat to global public health, especially through the inhalation of these substances in smoked products like cigarettes and marijuana. The World Health Organization (WHO) estimates that more than 25% of the global disease burden is linked to environmental factors, including exposure to toxic chemicals [26]. These toxic elements, commonly present in both natural and anthropogenic environments, have been shown to contaminate smoked substances, bypassing biological barriers during inhalation and resulting in rapid absorption into the bloodstream [13,27]. This exposure pathway has dire consequences, ranging from respiratory diseases to cardiovascular complications and neurological disorders [13]. This, therefore, becomes a public health threat, especially in low- and middle-income countries (LMICs), where regulatory frameworks are often inadequate.

Africa bears a disproportionate burden of PTEs contamination due to weak environmental regulations, industrial pollution, and limited oversight of consumable products. In Nigeria, contamination by PTEs in consumables presents a major risk to public health. For example, a study revealed that *Amaranthus* grown along major highways in Lagos contains elevated PTEs concentrations due to aerial deposition, underlining the role of urban pollution [28]. Similarly, crops near Bayelsa's Etelebou oil flow station, particularly cassava and plantain, exhibited excessive levels of Pb, Fe, Zn, and Cu, posing severe health risks to local populations reliant on these staples [28]. South Africa presents similar concerns, with dangerously high levels of Hg, Pb, and Cd detected in maternal and umbilical cord

blood, signaling threats to both adult and fetal health [29]. Across Sub-Saharan Africa, unchecked artisanal mining, industrial pollution, leaded fuel use, and inadequate environmental regulations have intensified PTEs contamination [30]. These widespread pollutants, compounded by weak policy enforcement, continue to endanger ecosystems and human health, demanding urgent and coordinated interventions.

Pb and Cd are two examples of PTEs that cigarettes and marijuana might release into the environment. The air and soil quality can be negatively impacted by the thousands of dangerous substances found in cigarette smoking, such as PTEs and radioactive elements, which can enter the environment through waste and smoke emissions [31]. According to a study that links marijuana usage to higher blood and urine concentrations of Pb and Cd, marijuana plants can absorb PTEs from contaminated soils, and users may be exposed to excessive amounts of these toxic elements [32]. Furthermore, it was discovered that cannabis products from Dutch coffee shops had dangerously high levels of Pb, pesticides, and potentially harmful bacteria [33]. These toxic substances can bioaccumulate in ecosystems, endangering the health of wildlife and humans. Therefore, effective regulation and monitoring of contaminants in tobacco and cannabis products are essential for protecting environmental and public health.

Although stringent regulations in the United States, PTEs contamination in smoked substances persists as a public health concern. Studies have detected As, Cd, Cr, Ni, and Pb in cigarettes consumed by U.S. smokers, with Cd and Pb posing risks due to their long biological half-lives and cumulative toxicity [13,34]. Additionally, research indicates that tobacco smoke exposure may elevate levels of PTEs in children's saliva, raising concerns about early-life exposure [35]. Similarly, studies on combusted cannabis reveal the presence of PTEs such as Se, Hg, Cd, Pb, Cr, Ni, and As, which present health risks, particularly to vulnerable populations such as cancer patients who may use cannabis for therapeutic purposes [27,34]. Likewise, Europe faces challenges stemming from historical industrial activities and environmental pollution, contributing to PTE contamination. A study reported elevated PTEs concentrations in cigarettes from various countries, including Europe. Cigarettes from Belgium and the UK showed remarkably higher Pb levels, while Cd concentrations were significantly elevated in those from Thailand, the UK, and Belgium [36]. Comparably, research in Saudi Arabia highlighted tobacco as a significant source of Cd and Pb pollution, estimating that smoking a single pack of 20 cigarettes delivers 1.40–2.70 µg of Cd to the smoker [37].

In Asia, contamination by PTEs in cigarettes demonstrates considerable variation across countries. Research in China identified consistently high levels of toxic metals in cigarettes from seven cities, with Cd averaging 3.24 µg/g (range 2.0–5.4 µg/g) and Pb averaging 2.54 µg/g (range 1.2–6.5 µg/g) [38]. In contrast, findings on Indian cigarettes revealed reasonably lower levels of Cd and Pb in Indian flue-cured tobacco [39]. Furthermore, a regional analysis outlined distinct trends—cigarettes from Thailand contained the highest Cd concentrations, Vietnam and Thailand reported elevated Hg levels, and South Korean cigarettes showed the highest Pb content among the sampled nations [34]. Collectively, these findings unveil the diverse contamination profiles across the globe, carrying important implications for public health and the regulatory framework.

## 1.2. Purpose of the Study

Despite the widespread consumption of cigarettes and marijuana in Bauchi State [1], data on the levels of PTEs in these substances remain limited. Our study addresses this gap by assessing the concentrations of selected PTEs (Cd, Cu, Zn, Fe, and Pb) in commonly consumed cigarettes and marijuana leaves from Bauchi State. Specifically, we aim to

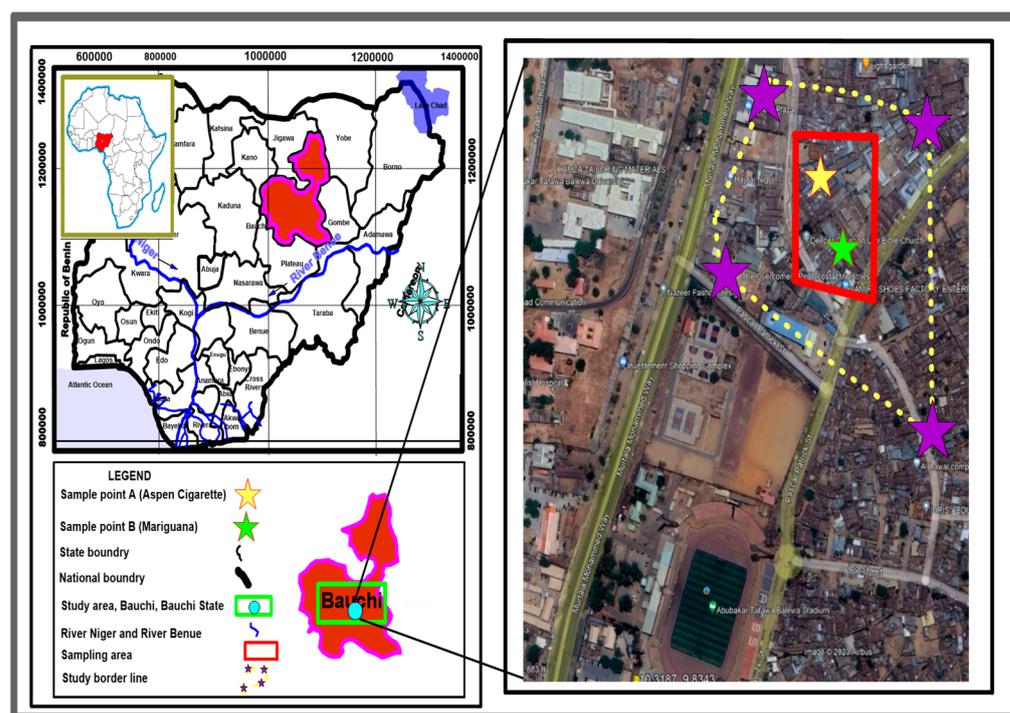
quantify these elements using an atomic absorption spectrophotometer (AAS) and discuss the potential impact of their inhalation on public health.

In doing so, our study contributes meaningful evidence that can shape policy decisions, stronger regulations, and greater public awareness around environmental health and public safety.

## 2. Materials and Methods

### 2.1. Study Area

Our study was conducted in Bayan Gari (Tudun Wadan Daniya), located within the Bauchi metropolis, Bauchi State, Nigeria, northeastern region of the country (Figure 1). The topography is characterized by undulating plains and isolated hills, typical of the Bauchi terrain, which is influenced by the continuation of the Jos Plateau to the southwest. The region experiences a tropical savanna climate with distinct wet and dry seasons. Rainfall varies from approximately 700 mm annually in the north to 1300 mm in the southern parts, with temperatures typically ranging between 57 °F and 100 °F (14 °C to 38 °C) [40]. The area is dominated by Sudan Savanna vegetation, with sandy loam soils derived from granite and basement complex rocks, prone to varying degrees of fertility and erosion. Urbanization and human activities, including agriculture, mining, and waste disposal, have significantly impacted the environmental conditions, making it an important site for studying soil contamination and PTEs distribution.



**Figure 1.** A map of the study area and the sample point.

### 2.2. Sample Collection and Preparation

The marijuana and cigarette sample (Aspen) was obtained from Bayan Gari (Tudun Wadan Daniya), Bauchi State, Nigeria, in May 2023. Aspen cigarettes (a menthol brand of cigarettes manufactured by the Lorillard Tobacco Company since 1979 and arguably the most popular in Nigeria) and Marijuana were purchased randomly from the local market in Bayan Gari, Bauchi state, with permission obtained from the Nigerian Drug Law and enforcement agency (NDLEA). Glassware and polyethylene (PE) containers were immersed in 2% nitric acid for 24 h, thoroughly rinsed with distilled water, and dried carefully to

prevent any potential contamination from the equipment. Sample B contained Indian Hemp (Marijuana), while Sample A contained cigarettes (Aspen). Sample preparation involved two key steps. First, tobacco cigarettes were placed in a microwave muffle furnace (refer to Table 1 for model) set at 500 °C for 20 min to ensure complete combustion, resulting in ashen material. This method of ashing is commonly used in studies assessing the elemental composition of plant materials, like the approach described in a patent for detecting ash content in tobacco [41,42]. The second step involved grinding *Cannabis sativa* samples to a fineness of 30 mesh using a mortar and pestle, which is consistent with the procedure described by [41] in their research on PTEs analysis in cannabis (Table 1).

**Table 1.** Laboratory equipment.

Equipment	Model	Manufacturer
Muffle furnace	Lenton ECF 12/10	Gallenkamp, Chicago, IL, USA
Mortar and pestle	Wood	Locally made
Hot plate	Oven BS (Welland series)	Gallenkamp, Chicago, IL, USA
Beaker	Glass 1000 series	Pyrex, Sunderland, UK
Volumetric flask	Glass Class A	Pyrex, Sunderland, UK
Spatula	Metal 2082	BJB Enterprises, Tustin, CA, USA
Weighing balance	Mettler PC 400	Gallenkamp, Chicago, IL, USA

### 2.3. Sample Digestion and Analysis

Five grams of Aspen tobacco cigarettes (sample A) were subjected to acid digestion using a 3:1 mixture of 69% HNO<sub>3</sub> (LC BDH Chemicals Limited, Poole, Dorset, UK) and 40% HCl (Arphilipharis reagent, London, UK). The mixture was heated to near dryness to ensure complete breakdown of the organic matrix. The digest was then filtered using a 0.45 µm PTFE syringe filter (DISMIC<sup>®</sup>-25HP, Roshi Kaisha Ltd., Tokyo, Japan) to remove particulates [43]. The filtrate was quantitatively transferred to a 200 mL volumetric flask and diluted to the mark with deionized water. For the cannabis sample (sample B), five grams were similarly digested using the same acid mixture, with stirring and heating for five minutes, followed by cooling in a fume cupboard. The digest was diluted to 25 mL with deionized water. Both digests were analyzed using atomic absorption spectrophotometry (AAS, Perkin Elmer, A-Analyst 400 series, Shelton, CT, USA). The resulting metal concentrations in solution were used to calculate the elemental content in the solid samples (µg/g), to ensure accurate and comparable quantification of trace metals per gram of dry material, in line with standard protocols [44,45].

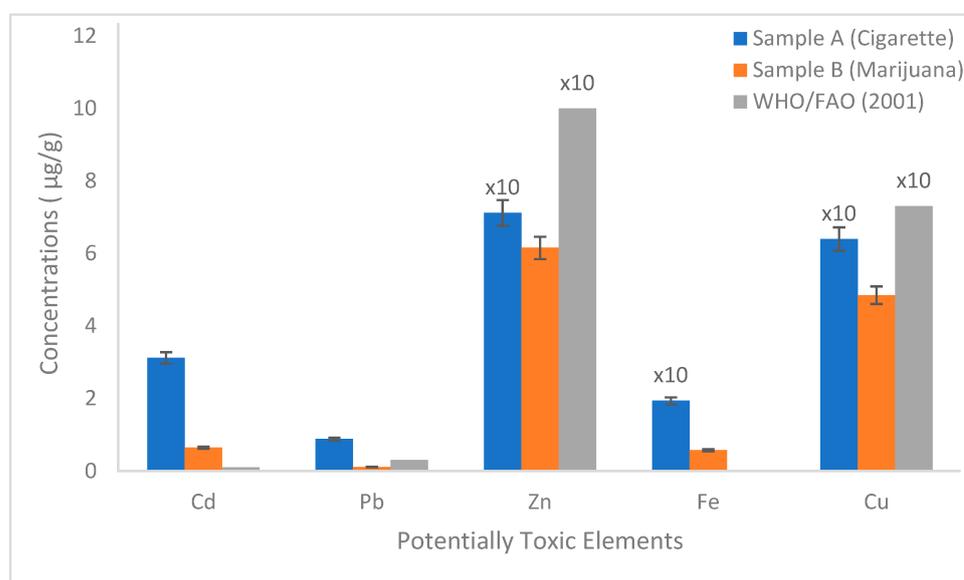
### 2.4. Statistical Analysis

We used a two-sample *t*-test and RStudio version (R-4.4.2) to compare the mean concentrations of PTEs and mean absorbance levels between the two sample types. For the PTEs analysis, the *t*-test was used to determine if there were statistically significant differences in the concentrations of metals (Cd, Pb, Zn, Fe, and Cu) between cigarette and marijuana samples. Similarly, the test was applied to assess differences in mean absorbance values for each metal between Sample A and Sample B. The *t*-test evaluates the null hypothesis that the means of the two groups are equal, with a significance level set at  $p < 0.05$ . A statistically significant *p*-value indicates that the observed differences are unlikely to have occurred by chance [46].

## 3. Results and Discussion

The analysis revealed variations in PTEs concentrations in the Aspen cigarette and marijuana (Indian hemp) samples, some of which exceeded permissible limits established by the WHO/FAO [47]. All PTE concentrations were measured in triplicate per sample.

Results were reported as mean values with error bars representing the standard error of the mean (SEM), ensuring both accuracy and reproducibility (Figure 2). These differences highlight potential health risks associated with the consumption of these substances and underline the importance of assessing environmental and agricultural contamination sources. The concentration of Cd in the Aspen cigarette sample (3.12  $\mu\text{g/g}$ ) was significantly higher than in marijuana (0.645  $\mu\text{g/g}$ ) (Figure 2), yet both exceeded the permissible limit of 0.01  $\mu\text{g/g}$  by WHO [47]. According to ref [48], Cd is a known carcinogen with no biological function in the human body. The study found unsafe Cd concentrations (0.38 to 1.205 mg/kg) in crops irrigated with wastewater exceeding WHO/FAO safety limits. It also reported that Cd had the highest health risk index (HRI: 6.10 to 13.85) among the metals studied, due to its bioaccumulation in edible plants, posing serious health risks for consumers. Similarly, ref [49] noted Cd accumulation in tobacco due to phosphate fertilizers. Chronic exposure to Cd through smoking or consumption of cannabis can lead to kidney damage, skeletal demineralization, and pulmonary effects. Moreover, its presence in smoke can contribute to environmental contamination through air and ash deposits.



**Figure 2.** The Bar graph visualizing mean concentrations of PTEs labeled Sample A (cigarette) and Sample B (Marijuana), ( $p < 0.01$ ). Note: Zn, Fe, and Cu in Sample A (Cigarette) and WHO/FAO (Zn and Cu) [47] are all in multiples of 10 ( $\times 10$ ) as indicated on the bar chart.

The Pb concentrations in the Aspen cigarette sample (0.88  $\mu\text{g/g}$ ) surpass the threshold limit of 0.03  $\mu\text{g/g}$  set by WHO/FAO [47]. Meanwhile, in marijuana, the concentration recorded was 0.11  $\mu\text{g/g}$ , which falls below the WHO/FAO threshold limit (Figure 2). Pb is a potent neurotoxin that accumulates in the body, particularly in the bones, and poses severe risks to neurological development, especially in children [50,51]. The findings align with prior studies, such as those by [27,52], which reported elevated Pb levels in various plant species grown in contaminated environments. Similar levels of tobacco might be due to Pb uptake from polluted soils, as observed in studies on urban farming practices in Africa [53]. Even at low levels, long-term exposure can impair cognitive function, damage the cardiovascular system, and affect kidney health [48]. As Pb accumulates in the environment, it can contaminate soil and water systems, disrupt ecosystems, and harm both plant and animal life [54].

Zn concentrations were significantly higher in Aspen cigarettes (71.2  $\mu\text{g/g}$ ) compared to marijuana (6.155  $\mu\text{g/g}$ ) (Figure 2), with both falling within the permissible range of 100.0  $\mu\text{g/g}$  set by [46]. Zn is an essential trace element necessary for enzymatic functions,

immune responses, and wound healing [55]. However, excessive Zn intake can disrupt Cu metabolism and cause gastrointestinal distress [56]. The higher Zn levels in cigarettes could result from the use of Zn-containing additives during tobacco processing. A practice reported in Iran by [57] found higher Zn concentrations in processed tobacco compared to raw leaves. In marijuana, Zn levels might reflect lower agricultural inputs or differences in soil composition [10,58]. Moreover, excessive exposure to Zn can disrupt plant growth and microbial balance in ecosystems [59].

Fe concentrations were significantly higher in Aspen cigarettes (19.36  $\mu\text{g/g}$ ) compared to marijuana (0.575  $\mu\text{g/g}$ ) (Figure 2). Both values were within acceptable limits (425  $\mu\text{g/g}$ ) established by [47]. Iron is crucial for hemoglobin synthesis and various enzymatic activities; though, excessive levels can induce oxidative stress and damage tissues [60]. The elevated levels in cigarettes might arise from contamination during curing processes or cultivation in iron-rich soils, consistent with observations by [61] in tobacco plantations. Hence, the lower levels of marijuana could indicate reduced environmental exposure or different cultivation practices [61]. In aquatic systems, elevated Fe can alter water quality and harm fish gills and microbial life [62]. Cu levels were higher in Aspen cigarettes (64  $\mu\text{g/g}$ ) compared to marijuana (4.85) (Figure 2), with both falling within the permissible range of 73  $\mu\text{g/g}$  [47]. Cu is essential for various biological functions, including enzymatic reactions and antioxidant defense mechanisms. Nonetheless, excess Cu can result in toxicity, manifesting as liver damage and gastrointestinal disturbances [63]. Elevated Cu levels in cigarettes may result from the use of Cu-based pesticides during tobacco cultivation, as noted in studies like [57,61]. Moreover, elevated Cu levels can harm both aquatic organisms and plants by disrupting fish gill function and reproduction, and by inhibiting root development [64].

Compared to the findings reported by [65], where marijuana samples exhibited high levels of Pb (7.9–10.2  $\mu\text{g/g}$ ) and Cd (3.2–4.7  $\mu\text{g/g}$ ), the current study reveals lower concentrations—Pb (0.11  $\mu\text{g/g}$ ) and Cd (0.645  $\mu\text{g/g}$ ) (Table 2). This contrast may be attributed to differences in environmental conditions, cultivation practices, regulatory frameworks, or geographic sourcing of the samples. Importantly, the current analysis also documented concentrations of Cu, Zn, and Fe, which are not detailed in [65], offering a broader understanding of PTEs present in locally available marijuana. Also, cigarette samples analyzed in this study contained 0.88  $\mu\text{g/g}$  of Pb and 3.12  $\mu\text{g/g}$  of Cd, levels that fall within the range of 0.44–2.64  $\mu\text{g/g}$  previously reported for Pb and higher than 0.86–1.81  $\mu\text{g/g}$  previously recorded for Cd [5,66] (Table 2). The primary sources of these contaminants in tobacco have been linked to uptake from contaminated soils, pesticide application, and the use of phosphate-based fertilizers during cultivation. Even at trace levels, Pb exposure is associated with neurodevelopmental deficits, elevated blood pressure, and cognitive impairment, particularly in children and adolescents [54]. Cd, on the other hand, is a recognized human carcinogen and has been implicated in kidney dysfunction, skeletal damage, and cardiovascular disease [67].

Beyond Pb and Cd, the study also quantified Cu, Zn, and Fe in both marijuana and cigarettes. While these metals are essential micronutrients, their inhalation during smoking or vaping bypasses normal metabolic regulation and may contribute to oxidative stress, pulmonary inflammation, and long-term respiratory toxicity, especially at elevated concentrations [68]. These findings emphasize the need for rigorous quality control measures and standardized regulatory oversight for both tobacco and cannabis products. The data presented in Table 2 highlight not only the variability in PTE concentrations across product types but also the potential health risks posed by chronic exposure. The presence of metals such as Cu, Zn, and Fe further illustrates the complexity of inhaled toxicant profiles and their implications for human health.

**Table 2.** Comparison of health effects of PTEs in marijuana and cigarettes.

Substance	Heavy Metal Concentration ( $\mu\text{g/g}$ )	Source of Contamination	Health Effects	Citation
Marijuana	Pb: 7.9–10.2; Cd: 3.2–4.7	Absorbed from soil during plant growth	Cancer, cognitive impairment, cardiovascular disease	[65]
Cigarettes	Pb: 0.44–2.64; Cd: 0.86–1.81; As: 0.17–0.86	Soil contamination, fertilizers used in tobacco cultivation	Lung cancer, cardiovascular diseases, neurological disorders	[5,66]
Cigarettes	Pb: 0.88; Cd: 3.12; Cu: 64, Zn: 71.2, Fe: 19.2	Application of additives during tobacco processing. Phosphate fertilizer and pesticides use during tobacco cultivation	Causes serious long-term health effects, especially via inhalation	Current study
Marijuana	Pb: 0.11; Cd: 0.645; Cu: 4.85, Zn: 6.155, Fe: 0.575	Low contamination	Causes serious long-term health effects, especially via inhalation	Current study

Consistent with global research, the PTE levels observed in this study reflect broader environmental contamination trends. Prior studies [8–10,43,51] have demonstrated that factors such as polluted irrigation water, industrial emissions, and the use of contaminated fertilizers significantly influence the accumulation of toxic elements in agricultural products. The observed variability in Zn, Fe, and Cu concentrations between marijuana and cigarette samples suggests differential exposure pathways and agricultural inputs, further supporting the need for localized monitoring strategies. Moreover, the environmental implications of PTE contamination are considerable. The elevated levels of Pb and Cd, though lower than in some literature, remain above ecological safety thresholds and may contribute to long-term pollution of air, soil, and water resources. Through combustion or improper disposal, these metals can enter ecosystems, where they have the potential to bioaccumulate and biomagnify, posing threats to both wildlife and human populations [3].

Given these multifaceted risks, this study highlights the urgent need for integrated public health policies and environmental protection strategies aimed at minimizing exposure to PTEs through consumable products.

#### *Study Limitations*

Although our study provided valuable insights into the concentrations of PTEs in marijuana and cigarette samples, highlighting both environmental and health risks posed by these substances, it also has several limitations. The sample size was limited to just two types of products from a single location, which may not be representative of broader trends across different regions or product variations. Additionally, the study focused on a limited range of PTEs, and future research could benefit from exploring a wider spectrum of contaminants to fully capture the extent of environmental pollution. The long-term health impacts of exposure to these substances were not fully examined, suggesting a need for further investigation (e.g., health risk assessment) in this area. These limitations indicate that, although the study contributes significantly to our understanding of contamination by PTEs, further research is needed to draw more generalized conclusions and to inform better public health strategies.

## **4. Conclusions**

Our findings revealed that Cd and Pb concentrations in both samples exceeded the permissible limits set by the WHO. Zn, Cu, and Fe concentrations were within or below permissible limits, depending on the sample. Notably, all potential trace elements examined in marijuana were significantly lower than in cigarettes. The study emphasizes the

toxicological implications of exposure to PTEs from both cigarettes and cannabis, with long-term health risks for smokers and those exposed to secondhand smoke. We therefore recommend the following measures to address the contamination of these products and mitigate associated health risks.

1. Strengthen and enforce quality control measures for tobacco and cannabis products to ensure PTE concentrations meet safe limits established by the WHO.
2. Launch targeted campaigns to educate the public about the health risks of PTEs exposure from smoking, emphasizing Cd and Pb toxicity.
3. Mitigate soil contamination by promoting clean irrigation, safe fertilizers, and regular monitoring of agricultural lands used for tobacco and cannabis cultivation.

**Author Contributions:** T.S.: Research design and writing the Methodology, Investigation, Conceptualization, and interpretation of the statistical aspect of the research. Y.A.A.: Involved in interpreting the analysis, research design, interpretation, and writing. F.O.: Editing and review. A.J.N.: Review and editing, Formal analysis. M.B.A.: Proofreading, Writing, and Investigation. U.A.O.: Designing and modifying the graphical aspect in representing the data collection on the study area map. B.O.A.: Partook in the arrangement and formatting of the in-take citations and the reference styles. F.A.: field mapping exercises and involved in data collection. H.Z.: Review, editing, and proofreading of the manuscript. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The data supporting the findings of this study are included and are available upon reasonable request from the corresponding author.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

AAS	Atomic Absorption Spectroscopy
Cd	Cadmium
COPD	Chronic Obstructive Pulmonary Disease
Cu	Copper
Fe	Iron
FAO	Food and Agriculture Association
Hg	Mercury
IARC	International Agency for Research on Cancer
IQ	Intelligence Quotient
LMIC	Low- and Middle-Income Countries
Pb	Lead
PTE.	Potentially Toxic Elements
UK	United Kingdom
US	United States
WHO	World Health Organization
Zn	Zinc

## References

1. Aliyu, A.S.; Umar, N.Y.; Sani, F.A.; Abubakar, U.U.; Umar, M.A. Epidemiological Study on the Prevalence of Cigarette Smoking and Factors Associated with It among Nursing Students at Aliko Dangote College of Nursing Sciences Bauchi State, Nigeria. *ARC J. Public Health Community Med.* **2020**, *5*, 8–17. [[CrossRef](#)]

2. Masindi, V.; Muedi, K.L. Environmental Contamination by Heavy Metals. In *Heavy Metals*; Hosam El-Din, M., Saleh Refaat Aglan, F., Eds.; IntechOpen: Rijeka, Croatia, 2018. [CrossRef]
3. Tchounwou, P.B.; Yedjou, C.G.; Patlolla, A.K.; Sutton, D.J. Heavy metal toxicity and the environment. In *Molecular, Clinical and Environmental Toxicology*; Luch, A., Ed.; Springer: Basel, Switzerland, 2012; pp. 133–164. [CrossRef]
4. Siame, T.; Muzandu, K.; Kataba, A.; M’kandawire, E. Comparative determination of human health risks associated with consumption of groundwater contaminated with lead in selected areas surrounding the former lead mine in Kabwe and non-mining areas in Lusaka, Zambia. *Int. J. Community Med. Public Health* **2023**, *10*, 4089. [CrossRef]
5. Järup, L. Hazards of heavy metal contamination. *Br. Med. Bull.* **2003**, *68*, 167–182. [CrossRef]
6. Das, S.; Sultana, K.W.; Ndhlala, A.R.; Mondal, M.; Chandra, I. Heavy Metal Pollution in the Environment and Its Impact on Health: Exploring Green Technology for Remediation. *Environ. Health Insights* **2023**, *17*, 11786302231201259. [CrossRef] [PubMed]
7. Siame, T.; Aminu, M.B.; Ogunsanya, T.I.; Isiaka, A.B.; Aduwa, S.; Akagbue, B.O.; Durodola, O.; Bolaji, O. A comparison of studies examining the effects of arsenic on global human health and specific regions in Nigeria. *GSC Adv. Res. Rev.* **2024**, *18*, 22–31. [CrossRef]
8. Adnan, M.; Xiao, B.; Xiao, P.; Zhao, P.; Li, R.; Bibi, S. Research Progress on Heavy Metals Pollution in the Soil of Smelting Sites in China. *Toxics* **2022**, *10*, 231. [CrossRef]
9. Ahmadi, M.; Akhbarizadeh, R.; Haghhighifard, N.J.; Barzegar, G.; Jorfi, S. Geochemical determination and pollution assessment of heavy metals in agricultural soils of southwestern of Iran 05 Environmental Sciences 0503 Soil Sciences. *J. Environ. Health Sci. Eng.* **2019**, *17*, 657–669. [CrossRef]
10. Barakat, A.; Ennaji, W.; Krimissa, S.; Bouzaid, M. Heavy metal contamination and ecological-health risk evaluation in peri-urban wastewater-irrigated soils of Beni-Mellal city (Morocco). *Int. J. Environ. Health Res.* **2020**, *30*, 372–387. [CrossRef] [PubMed]
11. Fei, X.; Lou, Z.; Xiao, R.; Ren, Z.; Lv, X. Source analysis and source-oriented risk assessment of heavy metal pollution in agricultural soils of different cultivated land qualities. *J. Clean. Prod.* **2022**, *341*, 130942. [CrossRef]
12. Xing, W.; Yang, H.; Ippolito, J.A.; Zhao, Q.; Zhang, Y.; Scheckel, K.G.; Li, L. Atmospheric deposition of arsenic, cadmium, copper, lead, and zinc near an operating and an abandoned lead smelter. *J. Environ. Qual.* **2020**, *49*, 1667–1678. [CrossRef]
13. Caruso, R.V.; O’Connor, R.J.; Stephens, W.E.; Cummings, K.M.; Fong, G.T. Toxic Metal Concentrations in Cigarettes Obtained from U.S. Smokers in 2009: Results from the International Tobacco Control (ITC) United States Survey Cohort. *Int. J. Environ. Res. Public Health* **2013**, *11*, 202–217. [CrossRef] [PubMed] [PubMed Central]
14. Ren, T.; Chen, X.; Ge, Y.; Zhao, L.; Zhong, R. Determination of heavy metals in cigarettes using high-resolution continuum source graphite furnace atomic absorption spectrometry. *Anal. Methods* **2017**, *9*, 4033–4043. [CrossRef]
15. Musah, B.I. Effects of heavy metals and metalloids on plant-animal interaction and biodiversity of terrestrial ecosystems—an overview. *Environ. Monit. Assess.* **2024**, *197*, 12. [CrossRef]
16. Okereafor, U.; Makhatha, M.; Mekuto, L.; Uche-Okereafor, N.; Sebola, T.; Mavumengwana, V. Toxic Metal Implications on Agricultural Soils, Plants, Animals, Aquatic life and Human Health. *Int. J. Environ. Res. Public Health.* **2020**, *17*, 2204. [CrossRef]
17. Shahjahan, M.; Taslima, K.; Rahman, M.S.; Al-Emran, M.; Alam, S.I.; Faggio, C. Effects of heavy metals on fish physiology—A review. *Chemosphere* **2022**, *300*, 134519. [CrossRef] [PubMed]
18. Angon, P.B.; Islam, S.; Kc, S.; Das, A.; Anjum, N.; Poudel, A.; Suchi, S.A. Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. *Heliyon* **2024**, *10*, e28357. [CrossRef]
19. International Agency for Research on Cancer (IARC). Cadmium and Cadmium Compounds (Group 1) 1993: 119. Available online: <https://www.inchem.org/documents/iarc/vol58/mono58-2.html> (accessed on 28 July 2025).
20. Tellez-Plaza, M.; Jones, M.R.; Dominguez-Lucas, A.; Guallar, E.; Navas-Acien, A. Cadmium Exposure and Clinical Cardiovascular Disease: A Systematic Review. *Curr. Atheroscler. Rep.* **2013**, *15*, 356. [CrossRef] [PubMed]
21. Lanphear, B.; Navas-Acien, A.; Bellinger, D.C. Lead Poisoning. *N. Engl. J. Med.* **2024**, *391*, 1621–1631. [CrossRef]
22. León, O.L.L.; Pacheco, J.M.S. Effects of Lead on Reproductive Health. In *Lead Chemistry*; Chooto, P., Ed.; IntechOpen: Rijeka, Croatia, 2020. [CrossRef]
23. Collins, J.F.; Klevay, L.M. Copper. *Adv. Nutr.* **2011**, *2*, 520–522. [CrossRef]
24. Plum, L.M.; Rink, L.; Haase, H. The Essential Toxin: Impact of Zinc on Human Health. *Int. J. Environ. Res. Public Health* **2010**, *7*, 1342–1365. [CrossRef] [PubMed]
25. Rafati Rahimzadeh, M.; Rafati Rahimzadeh, M.; Kazemi, S.; Moghadamnia, A.R.; Ghaemi Amiri, M.; Moghadamnia, A.A. Iron; Benefits or threatens (with emphasis on mechanism and treatment of its poisoning). *Hum. Exp. Toxicol.* **2023**, *42*, 9603271231192361. [CrossRef] [PubMed]
26. Mamtani, R.; Stern, P.; Dawood, I.; Cheema, S. Metals and Disease: A Global Primary Health Care Perspective. *J. Toxicol.* **2011**, *193*, 307. [CrossRef]
27. Pappas, R.S.; Fresquez, M.R.; Martone, N.; Watson, C.H. Toxic Metal Concentrations in Mainstream Smoke from Cigarettes Available in the USA. *J. Anal. Toxicol.* **2014**, *38*, 204–211. [CrossRef] [PubMed]

28. Atayese, M.; Eigbadon, A.; Oluwa, K.; Adesodun, J. Heavy metal contamination of amaranthus grown along major highways in Lagos, Nigeria. *Afr. Crop Sci. J.* **2010**, *16*, 225–235. [[CrossRef](#)]
29. Anyanwu, B.O.; Ezejiofor, A.N.; Igweze, Z.N.; Orisakwe, O.E. Heavy Metal Mixture Exposure and Effects in Developing Nations: An Update. *Toxics* **2018**, *6*, 65. [[CrossRef](#)] [[PubMed](#)]
30. Fasinu, P.S.; Orisakwe, O.E. Heavy Metal Pollution in Sub-Saharan Africa and Possible Implications in Cancer Epidemiology. *Asian Pac. J. Cancer Prev.* **2013**, *14*, 3393–3402. [[CrossRef](#)]
31. Dryburgh, L.M.; Bolan, N.S.; Grof, C.P.; Galettis, P.; Schneider, J.; Lucas, C.J.; Martin, J.H. Cannabis contaminants: Sources, distribution, human toxicity and pharmacologic effects. *Br. J. Clin. Pharmacol.* **2018**, *84*, 2468–2476. [[CrossRef](#)]
32. Nate, S. Untested, Unsafe? Cannabis Users Show Higher Lead and Cadmium Levels. *Environ. Health Perspect.* **2023**, *131*, 094001.
33. Oomen, P.; Andree, R.; Rigter, S.; Van Laar, M. An Experiment with a Closed Cannabis Chain: Baseline Report on Contaminant Analysis. Ministry of Justice and Security, The Hague: South Holland, The Netherlands, 2018. Available online: [https://www.government.nl/binaries/government/documenten/reports/2018/06/20/an-experiment-with-a-closed-cannabis-chain/Rapportage\\_Knottnerus\\_Closed\\_Cannabis\\_chain.pdf](https://www.government.nl/binaries/government/documenten/reports/2018/06/20/an-experiment-with-a-closed-cannabis-chain/Rapportage_Knottnerus_Closed_Cannabis_chain.pdf) (accessed on 28 July 2025).
34. Bengyella, L.; Kuddus, M.; Mukherjee, P.; Fonmboh, D.J.; Kaminski, J.E. Global impact of trace non-essential heavy metal contaminants in industrial cannabis bioeconomy. *Toxin Rev.* **2022**, *41*, 1215–1225. [[CrossRef](#)]
35. Gatzke-Kopp, L.M.; Riis, J.L.; Ahmadi, H.; Piccerillo, H.L.; Granger, D.A.; Blair, C.B.; Thomas, E.A. Environmental tobacco smoke exposure is associated with increased levels of metals in children’s saliva. *J. Expo. Sci. Environ. Epidemiol.* **2023**, *33*, 903–910. [[CrossRef](#)] [[PubMed](#)]
36. Dinh, Q.P.; Novirsa, R.; Jeong, H.; Nugraha, W.C.; Addai-Arhin, S.; Viet, P.H.; Tominaga, N.; Ishibashi, Y.; Arizono, K. Mercury, cadmium, and lead in cigarettes from international markets: Concentrations, distributions and absorption ability of filters. *J. Toxicol. Sci.* **2021**, *46*, 401–411. [[CrossRef](#)] [[PubMed](#)]
37. Ashraf, M.W. Levels of Heavy Metals in Popular Cigarette Brands and Exposure to These Metals via Smoking. *Sci. World J.* **2012**, *2012*, 729430. [[CrossRef](#)] [[PubMed](#)]
38. O’Connor, R.J.; Schneller, L.M.; Caruso, R.V.; Stephens, W.E.; Li, Q.; Yuan, J.; Fong, G.T. Toxic metal and nicotine content of cigarettes sold in China, 2009 and 2012. *Tob. Control.* **2015**, *24*, iv55–iv59. [[CrossRef](#)] [[PubMed](#)]
39. Raju, N.J.; Kofod, M.; Isenbeck-Schröter, M.; Müller, G. Heavy metal content of Indian cigarettes. *Toxicol. Environ. Chem.* **1999**, *72*, 215–219. [[CrossRef](#)]
40. WorldWeather. Bauchi, Nigeria, Minimum and Maximum Forecast Temperature Annually. 2024. Available online: <https://www.worldweatheronline.com/bauchi-weather/bauchi/ng.aspx> (accessed on 28 July 2025).
41. Altmaier, S. The Big Four Heavy Metals in Cannabis: Sample Preparation and Analysis via ICP-MS. *Cannabis Sci. Technol.* **2021**, *4*, 24–29. Available online: <https://www.cannabissciencetech.com/view/the-big-four-heavy-metals-in-cannabis-sample-preparation-and-analysis-via-icp-ms> (accessed on 28 July 2025).
42. Sharma, A.; Sharma, V. Forensic analysis of cigarette ash using ATR-FTIR spectroscopy and chemometric methods. *Microchem. J.* **2022**, *178*, 107406. [[CrossRef](#)]
43. Siame, T.; Muzandu, K.; Kataba, A.; Weisiyu, Q.; M’kAndawire, E. A comparative assessment of Lead (Pb) concentration and physicochemical parameters in groundwater from the Kabwe mine and Lusaka non-mine sites, Zambia. *Discov. Environ.* **2024**, *2*, 101. [[CrossRef](#)]
44. Hina, B.; Rizwani, G.; Naseeb, U.; Huma, A.; Hyder, Z. Application of Atomic Absorption Spectroscopy to determine Mineral and Heavy Metal distribution level of Medicinal Plants. *J. Anal. Tech. Res.* **2023**, *5*, 26–32. [[CrossRef](#)]
45. Anal, J.M.H.; Chase, P. Trace elements analysis in some medicinal plants using graphite furnace-atomic absorption spectroscopy. *Environ. Eng. Res.* **2016**, *21*, 247–255. [[CrossRef](#)]
46. Meier, E.; Vandrey, R.; Rubin, N.; Pacek, L.R.; Jensen, J.A.; Donny, E.C.; Hecht, S.S.; Carmella, S.G.; Murphy, S.E.; Luo, X.; et al. Cigarette Smokers Versus Cousers of Cannabis and Cigarettes: Exposure to Toxicants. *Nicotine Tob. Res.* **2020**, *22*, 1383–1389. [[CrossRef](#)]
47. WHO Food Additives and Contaminants. *Joint Codex Alimentarius Commission, FAO/WHO Food Standards Programme; ALINORM 01/12A*; WHO: Geneva, Switzerland, 2001.
48. Aftab, K.; Iqbal, S.; Khan, M.R.; Busquets, R.; Noreen, R.; Ahmad, N.; Kazimi, S.G.T.; Karami, A.M.; Al Suliman, N.M.S.; Ouladsmame, M. Wastewater-Irrigated Vegetables Are a Significant Source of Heavy Metal Contaminants: Toxicity and Health Risks. *Molecules* **2023**, *28*, 1371. [[CrossRef](#)]
49. Weggler, K.; McLaughlin, M.J.; Graham, R.D. Effect of Chloride in Soil Solution on the Plant Availability of Biosolid-Borne Cadmium. *J. Environ. Qual.* **2004**, *33*, 496–504. [[CrossRef](#)] [[PubMed](#)]
50. Silbergeld, E. Facilitative mechanisms of lead as a carcinogen. *Mutat. Res. Fundam. Mol. Mech. Mutagen.* **2003**, *533*, 121–133. [[CrossRef](#)]

51. Yabe, J.; Nakayama, S.M.; Ikenaka, Y.; Yohannes, Y.B.; Bortey-Sam, N.; Oroszlany, B.; Muzandu, K.; Choongo, K.; Kabalo, A.N.; Ntapisha, J. Lead poisoning in children from townships in the vicinity of a lead–zinc mine in Kabwe, Zambia. *Chemosphere* **2015**, *119*, 941–947. [[CrossRef](#)]
52. Atta, M.I.; Zehra, S.S.; Dai, D.-Q.; Ali, H.; Naveed, K.; Ali, I.; Sarwar, M.; Ali, B.; Iqbal, R.; Bawazeer, S.; et al. Amassing of heavy metals in soils, vegetables and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan. *Front. Plant Sci.* **2023**, *13*, 1080635. [[CrossRef](#)]
53. Srivastava, V.; Sarkar, A.; Singh, S.; Singh, P.; de Araujo, A.S.F.; Singh, R.P. Agroecological Responses of Heavy Metal Pollution with Special Emphasis on Soil Health and Plant Performances. *Front. Environ. Sci.* **2017**, *5*, 64. [[CrossRef](#)]
54. Needleman, H. Lead poisoning. *Annu. Rev. Med.* **2004**, *55*, 209–222. [[CrossRef](#)] [[PubMed](#)]
55. Fairweather-Tait, S.J. Zinc in Human Nutrition. *Nutr. Res. Rev.* **1988**, *1*, 23–37. [[CrossRef](#)] [[PubMed](#)]
56. Salgueiro, M.J.; Zubillaga, M.; Lysionek, A.; Sarabia, M.I.; Caro, R.; De Paoli, T.; Hager, A.; Weill, R.; Boccio, J. Zinc as an essential micronutrient: A review. *Nutr. Res.* **2000**, *20*, 737–755. [[CrossRef](#)]
57. Pourkhabbaz, A.; Pourkhabbaz, H. Investigation of toxic metals in the tobacco of different Iranian cigarette brands and related health issues. *Iran. J. Basic Med. Sci.* **2012**, *15*, 636–644.
58. Aboubakar, A.; Douaïk, A.; Mewouo, Y.C.M.; Madong, R.C.B.A.; Dahchour, A.; El Hajjaji, S. Determination of background values and assessment of pollution and ecological risk of heavy metals in urban agricultural soils of Yaoundé, Cameroon. *J. Soils Sediments* **2021**, *21*, 1437–1454. [[CrossRef](#)]
59. Alloway, B.J. *Zinc in Soils and Crop Nutrition*, 2nd ed.; International Zinc Association; International Fertilizer Association (IFA): Brussels, Belgium; Paris, France, 2008.
60. Liehr, J.; Jones, J. Role of Iron in Estrogen-Induced Cancer. *Curr. Med. Chem.* **2001**, *8*, 839–849. [[CrossRef](#)] [[PubMed](#)]
61. Rani, S.; Sisodia, R. Heavy Metal Contamination of Medicinal Plants in India—A Perspective. *Asian J. Water Environ. Pollut.* **2023**, *20*, 9–17. [[CrossRef](#)]
62. USEPA. Aquatic Life Criteria—Iron. Environmental Protection Agency. 2023. Available online: <https://www.epa.gov/wqc/aquatic-life-criteria-and-methods-toxics> (accessed on 28 July 2025).
63. Yang, Y.; Wu, J.; Wang, L.; Ji, G.; Dang, Y. Copper homeostasis and cuproptosis in health and disease. *MedComm* **2024**, *5*, e724. [[CrossRef](#)] [[PubMed](#)]
64. Giller, K.E.; Witter, E.; McGrath, S.P. Toxicity of heavy metals to microorganisms and microbial processes in agricultural soils: A review. *Soil Biol. Biochem.* **1998**, *30*, 1389–1414. [[CrossRef](#)]
65. Zerihun, A.; Chandravanshi, B.S.; Debebe, A.; Mehari, B. Levels of selected metals in leaves of *Cannabis sativa* L. cultivated in Ethiopia. *SpringerPlus* **2015**, *4*, 359. [[CrossRef](#)]
66. Proshad, R.; Zhang, D.; Uddin, M.; Wu, Y. Presence of cadmium and lead in tobacco and soil with ecological and human health risks in Sichuan province, China. *Environ. Sci. Pollut. Res. Int.* **2020**, *27*, 18355–18370. [[CrossRef](#)] [[PubMed](#)]
67. Järup, L.; Akesson, A. Current status of cadmium as an environmental health problem. *Toxicol. Appl. Pharmacol.* **2009**, *238*, 201–208. [[CrossRef](#)] [[PubMed](#)]
68. Gordon, T.; Fine, J.M.; Nadas, A. Metallic particles in inhaled air and their effects on health. *Environ. Health Perspect.* **2012**, *120*, 1669–1674.

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