

Lead Contamination in Environmental Matrices

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Abstract

Lead, a toxic heavy metal, poses significant dangerous to both environmental ecosystems and human health. Its persistence in the environment, coupled with its potential for bioaccumulation, are key factors contributing to its harmful impact. Given the interrelated nature of environmental components, lead can easily infiltrate the food chain, resulting in serious health risks for both humans and animals. This study aims to assess the concentration of lead across various environmental matrices including soil (both surface and profile), water (drinking, surface, groundwater, and packaged), vegetation, and aerosols in selected urban and industrial areas of Albania. A total of 250 samples were collected and analyzed using Atomic Absorption Spectrometry (AAS), with both flame atomic absorption spectrometry (FAAS) and graphite furnace atomic absorption spectrometry (GFAAS) employed for accurate and sensitive quantification of lead. The results reveal substantial variation in lead concentrations across the analyzed environmental components. The highest concentrations were detected in surface soils, profile soils, and aerosols, particularly in regions near industrial activities such as the metallurgical complex in Elbasan, the former battery production plant in Berat, and certain locations in Tirana. These findings highlight the elevated risk of lead contaminating the food chain and pinpoint specific areas at increased environmental and public health risk. Certified reference materials (CRMs) from the International Atomic Energy Agency (IAEA), which correspond to the environmental matrices being analyzed, were used to ensure the accuracy, precision, and reliability of the analytical procedures. This study underscores the critical need for continuous environmental monitoring and provides crucial data for identifying specific urban and industrial zones in Albania at risk of lead contamination. The results support the development of evidence-based strategies for environmental management and public health protection, promoting a cleaner, healthier environment by mitigating heavy metal pollution, especially lead, which remains highly toxic even at low concentrations.

1 Introduction

Lead is a trace element found in the Earth's crust, primarily in the form of ores such as galena (lead sulfide, PbS), as well as in ores of uranium and thorium [1]. Over the years, lead has been extracted from mines and used for a variety of purposes. These include the production of batteries, X-ray shielding in hospitals and nuclear facilities, the manufacturing of metallic sheets

and pipes, lead alloys, construction materials, and as an additive in polyvinyl chloride (PVC) and benzene in various industries. Lead is also used in functional ceramics, paints, glass and glazes, cosmetics, and ammunition [1], [2]. The primary sources of lead emissions into the environment are both natural processes and anthropogenic activities [1], [3]. Lead is present in various environmental media, including soil, atmospheric aerosols, surface and groundwater, and vegetation. Plants are capable of absorbing nutrients, water, and trace metals from the soil, air, and water sources. The biogeochemical cycling of elements between plants and their surrounding environment plays a vital role in ecosystem dynamics.

When elevated concentrations of heavy metals are present in the soil, plants may accumulate significant amounts through root uptake, often in association with organic matter. However, the transport of metals to the aerial parts of the plant is often limited [4]. The increased accumulation of trace elements in soils can adversely affect plant growth and development, alter the elemental composition of harvested crops, and, in the case of food or feed plants, potentially lead to contamination of the food chain [5].

Lead can enter the food chain via uptake by plants and animals through nutrients and water. Environmental exposure to lead causes a wide range of adverse effects on environmental media and human health, depending on both the concentration of lead and the duration of exposure [6]. Heavy metals may also reach the food chain through contaminated drinking water, inhalation, and consumption of food. In humans and animals, the principal exposure pathways for lead are respiratory intake, ingestion via water, and consumption of contaminated foodstuffs [7, 8].

The aim of this manuscript is to assess lead concentrations in various environmental media and to identify and evaluate areas contaminated by lead. Particular emphasis is placed on analyzing lead concentrations in aerosols, vegetation, soil, and water samples and comparing them with standards recommended by the European Council Directives, the Environmental Protection Agency (EPA), and the World Health Organization (WHO) [9-12]. Furthermore, this work examines the analytical potential of atomic absorption spectroscopy (AAS) in monitoring lead levels, and highlights contaminated regions based on environmental assessments and calculated hazardous factors.

2 Materials and Methods

Representative environmental samples were collected from the urban areas of Berat, Elbasan, Tirana, Shkodra, and Pogradec in Albania. In Elbasan and Berat, samples were specifically taken from areas near local factories. Sampling points were selected across various environmental media (soil, water, aerosols and vegetation).

In total, 247 environmental samples were collected: 53 soil samples (33 surface and 20 profile samples), 31 aerosol samples (from the cities of Tirana and Elbasan), 61 vegetation samples

(including random and agricultural vegetation, with most collected near the former battery production facility), and 81 water samples (comprising 27 surface water samples, 32 tap water samples, 11 groundwater samples, and 11 bottled water samples).

All samples were analyzed for lead content using atomic absorption spectrometry (AAAnalyst 800, Perkin-Elmer), employing the graphite furnace method (GFAAS) with an auto-sampler (AS800) and graphite tube [16]. For analytical quality control, standard reference materials provided by the International Atomic Energy Agency (IAEA) were used, including IAEA Soil-7, IAEA-356, and IAEA-359, as well as the AA Test Mix reference solution (Perkin-Elmer), selected based on the sample matrix. Internal standards were used for aerosol sample analysis, and results were compared with those obtained from other analytical techniques. A matrix modifier was applied, following standard GF-AAS conditions, to minimize interference. The analytical procedures for digesting representative environmental samples are described below.

2.1 Digestion of soil Samples

Approximately 1 gram of dry soil sample was placed in a digestion vessel, and 10 mL of a 1:1 solution of HNO₃ (nitric acid) was added. The mixture was stirred to form a slurry and covered with a watch glass. The sample was then heated to 95 ± 5 °C and refluxed for 10 to 15 minutes without boiling. After allowing the sample to cool, 5 mL of concentrated HNO₃ was added, the watch glass was replaced, and the mixture was refluxed for an additional 30 minutes. After brown fumes were appeared, indicating oxidation by nitric acid, the addition of 5 mL of concentrated HNO₃ was repeated.

The sample was subsequently heated to 180 ± 5 °C and either allowed to evaporate to a volume of approximately 2–3 mL without boiling or maintained at this temperature without boiling for two hours. After cooling, the digested solution was quantitatively transferred to a 50 mL volumetric flask and brought to volume with distilled water.

This soil digestion procedure follows the method recommended by the United States Environmental Protection Agency (EPA) and was applied as the standard acid extraction technique [19].

2.2 Digestion of Biological Samples

Each of the dry vegetation samples (0.5 g) was weighed and placed in a glass beaker, to which 10 mL of concentrated HNO₃ (nitric acid) was added. The glass beakers were placed on a hot plate and heated for approximately 1 to 2 hours, until the sample volume was reduced to about 2–3 mL. After cooling to room temperature, 2 mL of hydrogen peroxide (H₂O₂) was added to each beaker, and the samples were reheated until the wet digestion process was complete and only a small volume remained. The digested solution was then quantitatively transferred to a 25 mL volumetric flask and brought to volume with distilled water. Finally, the solution was filtered and transferred to the atomic absorption laboratory for lead analysis [18].

2.3 Digestion of Aerosols Samples

The air filter samples were cut into small pieces and digested in 100 mL of hydrochloric acid (HCl) over low heat for 30 minutes. The resulting solution was removed, and the remaining solids were extracted three times with deionized water, each extraction lasting 15 minutes. The HCl solution and the water extracts were then combined and evaporated nearly to dryness.

The residue was dissolved in 10 mL of HCl, followed by the addition of 10 drops of nitric acid (HNO₃). The solution was then quantitatively transferred to a 50 mL volumetric flask and brought to volume with deionized water.

Digestion of the air filter paper samples was performed according to the Atomic Absorption Spectrometry (AAS) analytical method [17].

2.4 Digestion of Water Samples

Water samples were collected in 1 L polyethylene bottles. All groundwater samples were filtered, and their pH values were measured, ranging from 6.9 to 7.8. The samples were then acidified with nitric acid to a pH of approximately 2, after which methyl isobutyl ketone was added.

A 200 mL aliquot of each water sample was transferred to a 400 mL glass beaker, and 4 mL of concentrated HNO₃ was added. The samples were then digested on a hot plate for approximately 2 hours, until the volume was reduced to 2-3 mL. After cooling to room temperature, 1 mL of concentrated HCl was added. The digested solution was then quantitatively transferred to a 25 mL volumetric flask and diluted to the mark with double-distilled water [20].

For analytical quality control, the AA Test Mix reference standard solution (Perkin - Elmer) was used. To minimize matrix interference, a matrix modifier was applied according to standard conditions for graphite furnace atomic absorption spectrometry (GF - AAS).

3 Results

During the experimental work were analyzed standard calibration solutions, reference standard materials and environmental samples and found the total concentrations of lead in the representative environmental samples. In the Table 1 is presented the maximum, minimum and average fractions of lead concentration are found in different parts of environmental samples, while in Figure 1 these data are presented in graphical form.

From the results obtained it could be observed a significant variation in lead concentrations across different environmental media, indicating both spatial and source-related differences in contamination.

Table 1 Maximum, minimum and average lead concentration in environmental media samples.

Environmental media	Max.	Min.	Average
Surface soil	24207	105	1762
Profile Soil	52982	78	4664
Vegetable	4572	0.11	1196
Aerosols	2705	1.8	374
Water	11.8	0	1.6

Profile soil samples showed the highest levels of lead contamination, with a maximum concentration of 52,982 ppm and an average of 4,664 ppm. This suggests a long-term accumulation of lead in deeper soil layers, likely due to industrial activities or historical pollution that has been transported downward into the subsoil.

Surface soil samples also represented high lead concentrations, with a maximum of 24,207 ppm and an average of 1,762 ppm, indicating recent lead deposition, possibly from atmospheric pollution, industrial emissions, or locally waste treatment.

Vegetation samples showed a wide range of lead levels, from 0.11 ppm to a maximum of 4,572 ppm, with an average concentration of 1,196 ppm. This suggests that plants near industrial or contaminated areas, are absorbing significant amounts of lead from the soil and atmosphere. Such levels present potential health risks if these plants are consumed by living organisms.

Aerosol samples presented lead concentrations ranging from 1.8 to 2,705 ppm with an average of 374 ppm. These results represent considerable air pollution in urban and industrial areas, induced by emissions from traffic, factories, or the use of leaded gasoline.

Water samples showed relatively low lead concentrations, with a maximum of 11.8 ppm and an average of 1.6 ppm. Although the levels are lower compared to other environments, the presence of lead in water is still present potential health risks.

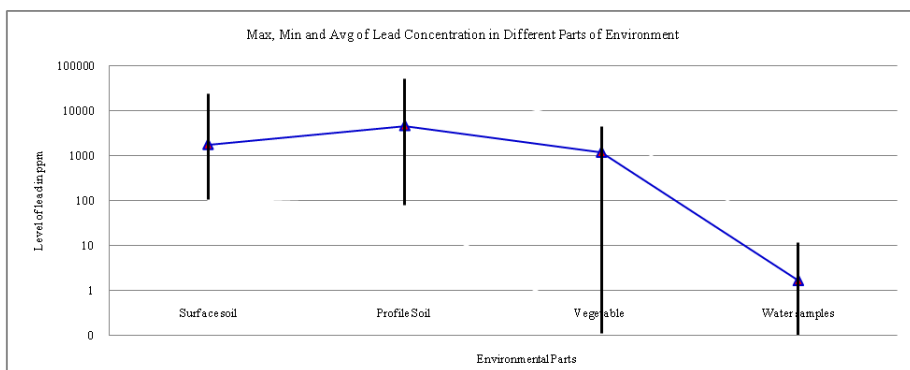
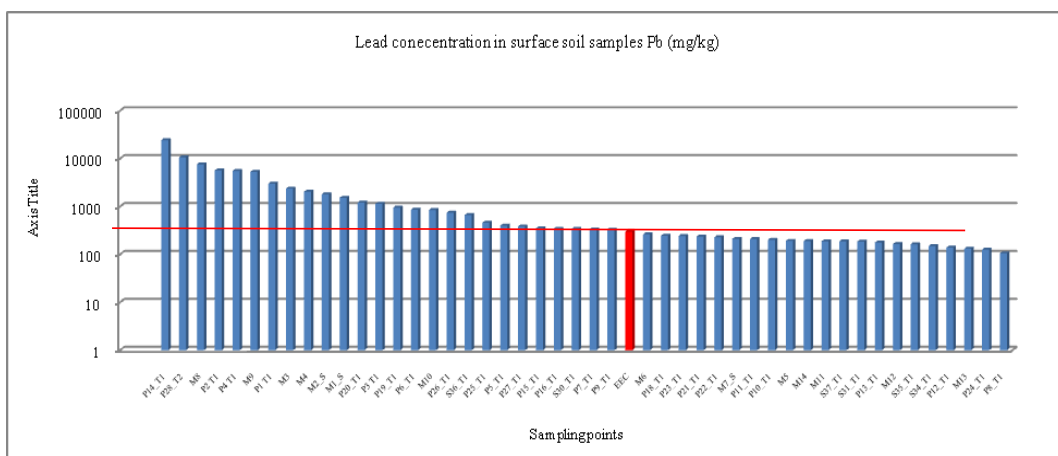


Figure 1 Maximum, minimum and average lead concentration in environmental media samples.

3.1 Results in soil (surface and profile) samples

The highest concentration of lead was found in samples collected from the industrial area, where waste disposal has occurred in an uncontrolled manner. It is believed that solid waste from the factory has mixed with the soil in this region. The areas from which samples were collected are not used for crop cultivation but rather for livestock feed. Lead concentrations in agricultural lands are lower, or at levels consistent with the recommended maximum contaminant level (MCL). Historically, this area was used for growing crops and vegetables for both livestock and local inhabitants.

Figs 2 and 3 present graphs of the lead concentrations found in the respective surface and profile soil samples.



In the Figure 4 is presented the calculated hazardous factor of lead in the representative surface soil samples.

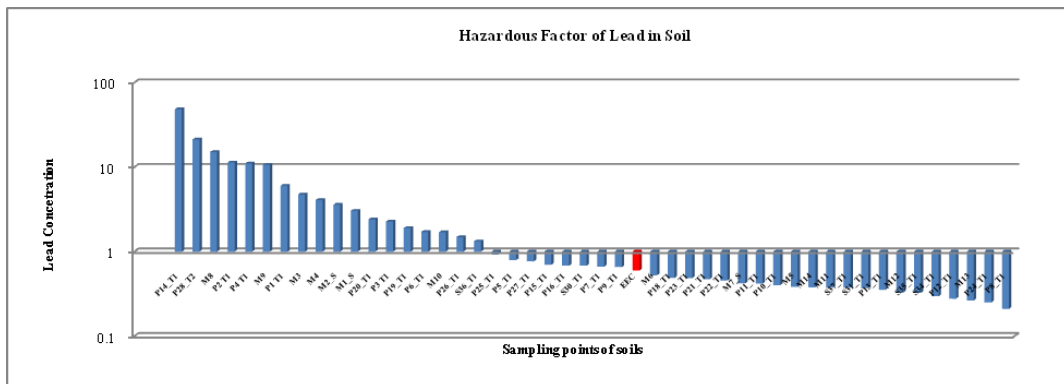


Figure 4 Calculated Hazardous factor in surface soil samples.

3.2 Results in vegetable samples

Figure 5 shows a graphical representation of the lead concentrations found in the representative vegetation samples, while Figure 6 shows the calculated bioaccumulation factor (BAF) from soil to plant. In some cases, lead concentrations in vegetation samples exceeded the maximum contaminant level (MCL) recommended by the EU Directive.

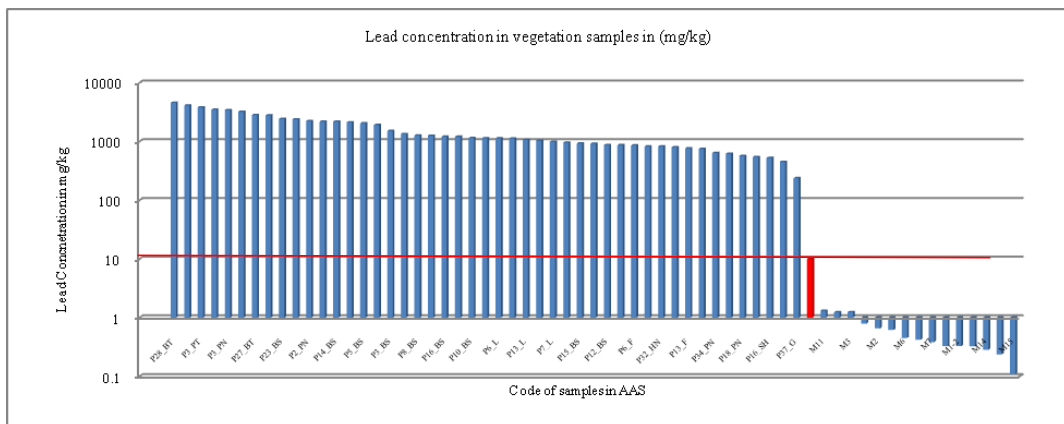


Figure 5 Fraction of lead in the responsible vegetation samples.

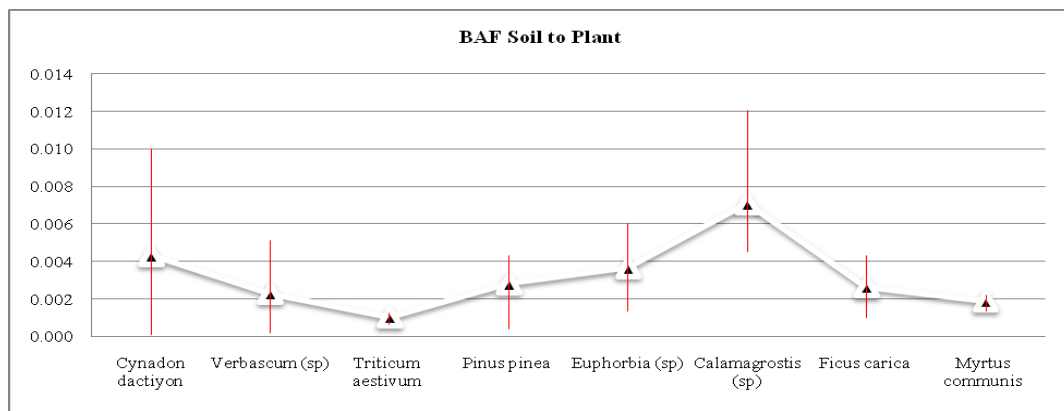


Figure 6 Calculated Bioaccumulation factor soil to plant.

The primary sources contributing to lead contamination in vegetation samples were contaminated soil and air pollution, particularly around the site of the former battery production factory. Plants absorb nutrients and water from the soil, and the aerial parts of plants also absorb humidity, airborne pollution, particles, and other elements present in the atmosphere. The capacity for lead uptake and accumulation depends on factors such as plant species, weather conditions, and soil pH.

The ability of various plants to accumulate lead, in descending order, was as follows: *Setaria* (sp.) > *Cynodon dactylon* > *Myrtus communis* > *Pinus pinea* > *Verbascum* (sp.) > *Triticum aestivum*. By calculating the average BAF (soil to plant), it was observed that lead accumulates in plants at varying levels.

3.3 Results in aerosols samples

Figure 7 show a graphical representation of lead concentrations in aerosol samples collected from Elbasan and Tirana cities. Figure 8 shows the hazardous factor of lead in the analyzed aerosol samples. Lead levels in the aerosol samples collected in Elbasan were higher than those in samples collected in Tirana. The most contaminated area was near the metallurgical combine. In descending order, the lead concentrations were ranked as follows: Elbasan Metallurgical > Elbasan Center > Tirana Center > Mount of Dajt.

The activity of the former metallurgical combine significantly contributed to the emission of gases and the release of solid waste around the industrial area. Other major sources of metal-related air pollution in both Elbasan and Tirana included emissions from fuel combustion, burning of urban waste, dust particles transported by wind, as well as construction and inert materials.

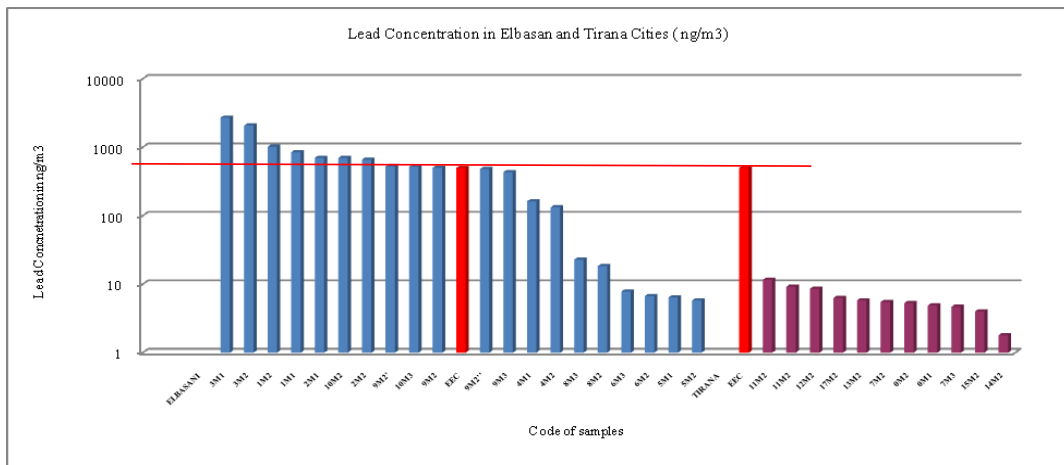


Figure 7 Fraction of lead in the responsible aerosols samples.

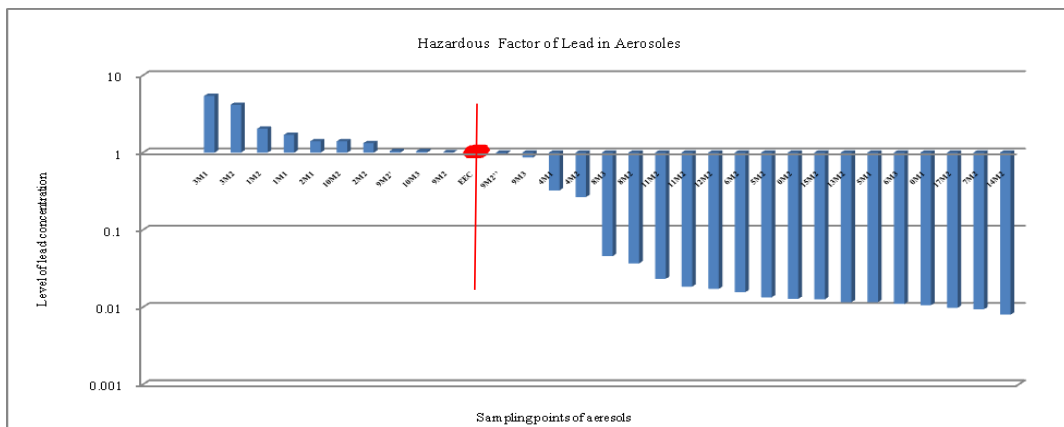


Figure 8: Calculated hazardous factor of lead in the aerosols samples.

3.4 Results in water samples

From the obtained results after we analyzed representatives of water samples (surface, tap, ground and bottle water) observed the presence of Pb in most of the samples. In the figure 9 is presented the fraction of lead concentration in the water samples. The mean concentration level of lead in water samples is compared with the maximum concentration level specified by WHO and EPA. No of the analyzed samples contained metals above maximum concentration level for drinking water standard. Fractions of lead in the surface and groundwater samples are contributed by anthropogenic processes, such as agriculture, transport, construction, and buildings (including housing), in these areas. Natural sources of lead in surface and groundwater were attributed to compounds found in sediments, geological formations, and rocks.

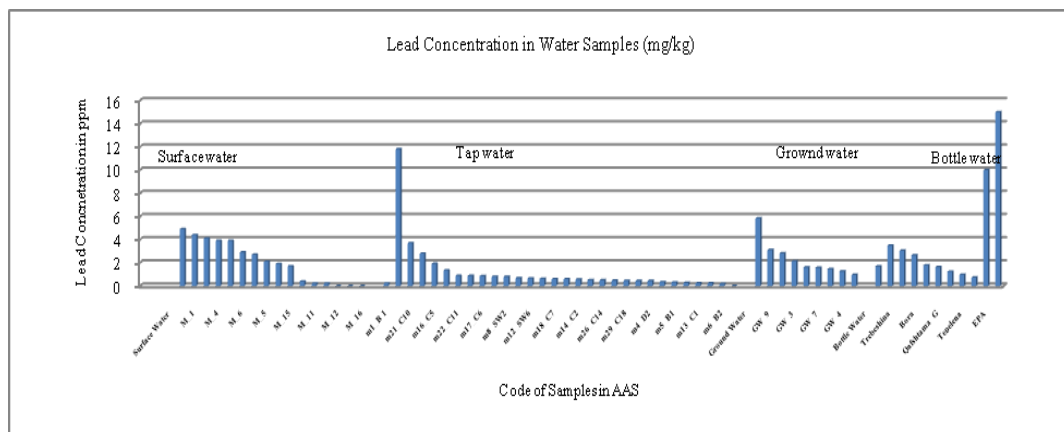


Figure 9 Fraction of lead concentration in the water samples.

Conclusions

This study provides a comprehensive assessment of lead concentrations across various environmental media, including soil, vegetation, aerosols, and water samples. The results indicated that lead contamination is widespread across the studied sites, with concentrations not uniformly distributed. Lead was detected in most of the representative environmental samples, and the concentrations were compared against the maximum allowable levels set by respective European Commission directives.

Lead concentrations in both surface and profile soil samples were found to be influenced by both natural and anthropogenic sources. The area surrounding the former Battery Production Factory in Berat, Albania, exhibited high levels of contamination, with both surface and profile samples showing elevated concentrations. Agricultural soils, however, had lead concentrations that were generally below the maximum permissible levels set by the EEC. Contributing factors included proximity to the industrial site, agricultural practices (such as crop cultivation and fertilization), and local atmospheric conditions.

Lead concentrations in vegetation samples were strongly correlated with lead levels in soil and aerosols. Additionally, the type and species of vegetation, along with atmospheric conditions, played a significant role in the accumulation of lead. Anthropogenic factors, such as the operation of the metallurgical industry and the uncontrolled disposal of industrial waste, were identified as major contributors to the contamination. It was noted that vegetation not only absorbed lead from contaminated soil but also from airborne particles and dust.

In the aerosol samples, lead concentrations were primarily influenced by the activities of the metallurgical combine, along with other anthropogenic sources such as fuel combustion, urban waste burning, and dust transport by wind. Weather conditions also contributed to the distribution of lead in the air. These findings highlight the significant impact of industrial activities and local pollution sources on atmospheric lead levels.

Lead concentrations in water samples were linked to several factors, including the condition and material of drinking water pipelines, network wear and tear, and occasional disruptions to the water supply system. Uncontrolled waste disposal around surface water bodies and runoff caused by specific atmospheric conditions also contributed to elevated lead levels in water sources. These factors underscore the role of infrastructure and environmental management in determining water quality.

The contamination of environmental media with lead is predominantly driven by anthropogenic sources, especially the uncontrolled waste disposal around areas affected by past industrial activities. The prolonged presence of lead in these environments poses significant ecological and human health risks.

The calculated Hazardous Factor for surface soil samples was found to be greater than 1, indicating that the territory is highly contaminated and poses serious ecological and human health risks. These findings are consistent with previous research that highlights the long-term negative effects of lead contamination on ecosystems and human populations [21], [22].

Author contributions

M. Alushllari: Conceptualization, Data Curation, Investigation, Methodology, Formal Analysis, Writing – Original Draft, S. Mico: Data Curation, Investigation, Methodology, Formal Analysis, Writing – Original Draft.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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