DOI: http://doi.org/10.21698/simi.2025.ab28

ATMOSPHERIC DEPOSITION AND THE EFFECTS OF METAL IONS BIOACCUMULATION ON THE ENVIRONMENT

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Keywords*: bioaccumulation, effects, emission sampling, heavy metals, incineration, immision sampling*

Introduction

The aim of present study analyzes the dynamics of metal ion concentrations in the emissions from an industrial waste incinerator and in the surrounding air over a three-year period (2022–2024) in the South-West of Romania, with a focus on seasonal variations and the efficiency of implemented control measures. The study also focuses to provide an accurate assessment of the disturbances caused to the geochemical cycles of metals within ecosystems, as well as their impact on human health and biodiversity. The results also contributed to the development of environmental strategies and policies aimed at reducing exposure to these contaminants. To assess the impact of these pollutants, metal ions were collected using specific absorbent solutions at the emission source, represented by a waste incinerator. The analysis targeted the most frequently detected metal species, including As, Mn, Pb, Cd, and Cr. These metals reached the atmosphere and were subsequently deposited on terrestrial surfaces through various physical and chemical processes, including atmospheric deposition, precipitation, and bioaccumulation, following the adsorption of airborne aerosols as represented in Figure 1. Metal ions were found in the atmosphere associated with suspended particulate matter, particularly PM_{10} and $PM_{2.5}$. Their environmental cycling was complex and multifactorial, involving continuous physical and chemical transformations that influenced their spatial distribution, bioavailability, and ecotoxicological impact on ecosystems and human health. Common sources of atmospheric metal pollution included waste incineration, metal smelting, the combustion of fuels from stationary sources (which predominantly emitted As, Cd, Cr, and Ni), and gasoline combustion, which resulted in significant Pb emissions. Incineration represented one of the most widespread sources of metal pollution. This process was defined as a rapid oxidation reaction between waste materials and air at high temperatures, which fully combusted

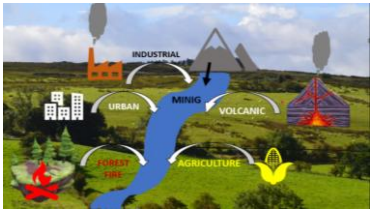

Figure 1. Distribution and Transport of Metals (Original source)

organic matter and converted non-combustible materials into stable inorganic residues.

Materials and methods

The sampling of metal concentrations, including As, Mn, Pb, Cd, and Cr, in the air was carried out using two methods: from emissions at the incinerator stack (emission sampling) and from the ambient air (immission sampling) in stable conditions. The immission sampling were collected from three points located at different distances from the incinerator (P1 – access gate, P2 – 30 m north of the incinerator, P3 – 20 m east of the incinerator). Metal ions were extracted from PM10 suspended particulate matter in the periods of July - December. Emission sampling was performed four times per year in the period of March, July, November and December, using an isokinetic method directly from the incinerator's exhaust stack. A controlled-volume suction pump was used in accordance with the SR EN 14385:2004/C91:2014 standard, operating at a flow rate of 1–3 L/min for a duration of 60 minutes. Immission sampling of metal ions was conducted twice per year—once during the warm season and once during the cold season—according to the SR EN 14902:2006 standard. This standard involves measuring metal ions in the PM10 fraction by aspirating a known volume of ambient air through a filter placed in a high-volume air sampler over a 24-hour period. Sample analysis was performed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), a highly sensitive technique used to detect and quantify trace-level elements. The method involved aspirating the analyte solution into the plasma, with three replicate measurements conducted per sample to ensure accuracy and repeatability.

Results and conclusions

Metal species concentrations decreased with distance from the incinerator, remaining below legal limits (500 µg/Nmc; 50 µg/Nmc).

The results obtained during the 2022–2024 monitoring period highlighted notable temporal variations. In the emission samples, Pb was found to be the most abundant species throughout the entire period (with a percentage of 44% in 2022 and 2023 and 55% in 2024), followed by Mn in 2022 and 2024 with a percentage of 28% respectively 30%, and by Cr in 2023 with a percentage of 32%. Regarding ambient air (immission) measurements, Mn showed a marked prevalence in 2022 and 2023 with percentage of 42% and 49%, whereas Cr became the dominant species in 2024 with a percentage of 61%. The lowest concentration recorded in both emission and residue samples during the monitoring period was that of As, with a percentage ranging between 0–5%, being considered insignificant.

In conclusion, the measured levels were influenced by environmental conditions, incinerator operation, the nature of the waste and the specific characteristics of each metal section. Metal ions can travel long distances, making it difficult to identify emission sources and highlighting the need for a detailed analysis of their spatial and temporal distribution.

Our results can be correlated and compared with the findings of the review article by Jones and Harrison in 2016, which indicate that ultrafine particle emissions from municipal solid waste incinerators are generally low due to efficient filtration and gas-absorbing materials, with ambient air being dominated by urban sources. Heavy metal pollution represented a major global concern, with significant implications for environmental quality and public health.