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Comparative Geochemical Pathways and Biological Interactions of Zinc, Lead, and Copper in Terrestrial and Aquatic Ecosystems

[1]Rajeshwari B, [2]Dr. Swapnila
[1]*Research Scholar of NIILM UNIVERSITY, KAITHAL*
[2]*Assistant Professor, Department of Chemistry, NIILM UNIVERSITY, KAITHAL*

Abstract:
This research focused on the analysis of concentration levels of heavy toxic elements, specifically Zinc (Zn), Lead (Pb), and Copper (Cu), in various environmental matrices. The study aimed to assess the extent of contamination, identify potential sources, and evaluate the implications for human health and the environment. Through the collection of soil, water, and air samples from selected sites, the concentrations of Zinc, Lead, and Copper were determined using appropriate analytical techniques. The results revealed spatial variations, with higher concentrations observed in industrial and urban areas, indicating the influence of anthropogenic activities. Soil samples exhibited the highest concentrations, followed by water and air samples. The elevated Zinc concentration levels have significant implications for human health, as prolonged exposure can lead to adverse effects such as gastrointestinal issues and immune system disruption. Furthermore, the contamination poses risks to the environment, particularly in aquatic ecosystems, where Zinc can be toxic to aquatic organisms. The findings underscore the importance of effective pollution control measures, improved waste management, and stricter regulations to mitigate Zinc contamination. Addressing the identified sources, such as industrial discharges and agricultural runoff, is crucial for safeguarding human health and preserving ecosystem integrity. Future research should focus on long-term trends, the effectiveness of remediation measures, and the development of sustainable technologies. This study contributes to the existing knowledge on heavy metal pollution, specifically Zinc, providing valuable insights for policymakers, industry stakeholders, and environmental agencies to formulate targeted strategies for pollution prevention and environmental protection.
Keywords: *Heavy metals, Concentration level, Zn, PB, Cu, environmental pollution*

I. INTRODUCTION

Industrial development and urbanization have given rise to environmental issues of immense concern. Among the spectrum of environmental pollutants, heavy metals such as Zinc (Zn), Lead (Pb), and Copper (Cu) have received widespread attention due to their potential for bioaccumulation and consequent deleterious effects on human health and the environment (Nriagu, 1988; Tchounwou et al., 2012).

These heavy metals are naturally occurring elements, yet their concentrations have been augmented significantly by anthropogenic activities, particularly in industrial sectors including manufacturing, construction, and agriculture (Jarup, 2003). For example, Zinc is essential in processes such as battery production and galvanizing steel (Maret & Sandstead, 2006), Lead is utilized in battery manufacture and radiation shields (Flora et al., 2012), while Copper's high conductivity makes it indispensable in electrical wiring and plumbing industries (Gaetke & Chow, 2003).

However, the environmental discharge of these elements during production processes or from waste repositories can result in elevated concentrations in the environment, consequently infiltrating the human food chain and leading to severe health implications (Jaishankar et al., 2014). Therefore, the analysis of the concentration levels of these heavy toxic elements has become an urgent and vital area of research. This study aims to investigate the concentration levels of Zn, Pb, and Cu in selected environments and discuss their potential implications on human health and the ecosystem.

Zinc, Lead, and Copper are extensively used in several industrial and commercial applications. Zinc is integral to processes like battery production and galvanization of steel, Lead is frequently utilized in battery manufacturing and radiation shielding, while Copper, known for its high conductivity, is a staple in electrical wiring and plumbing industries. However, the unchecked discharge of these elements during production processes or from waste repositories can escalate their environmental concentrations, ultimately seeping into the human food chain and causing potential health hazards.

Therefore, the analysis of the concentration levels of these heavy toxic elements is an urgent and significant research area. This study is aimed at investigating the concentration levels of Zn, Pb, and Cu in selected environments, thereby contributing valuable data to the understanding of these elements' ecological and health impacts.

In our rapidly modernizing world, the increased industrial and agricultural activities have led to a significant elevation in environmental pollutants, with heavy metals such as Zinc (Zn), Lead (Pb), and Copper (Cu) being among the most concerning. These metals, although occurring naturally, have seen their levels surge in the environment, posing significant threats to ecosystems and human health.

The vast application of these heavy metals across numerous industries underscores their essential role in modern economies. Zinc is instrumental in the pharmaceutical industry and for steel treatment, Lead's properties make it invaluable for battery production and radiation shielding, and Copper, due to its excellent conductivity, plays a crucial role in the electronics sector. However, the improper handling and disposal of these metals can result in their increased presence in the environment, leading to a range of deleterious effects.

Given this context, assessing the concentration levels of Zn, Pb, and Cu in the environment is critical. This study is designed to analyze the environmental concentrations of these heavy metals in selected regions, providing valuable insights into the magnitude of contamination. The findings of this research will not only enhance our understanding of heavy metal pollution but also inform policy-making and future efforts to mitigate the environmental impact of these toxic elements.

1.1 Significance of the Study

Human Health: Heavy metals like Zinc, Lead, and Copper can cause serious health problems in humans when exposure exceeds certain levels. Lead, for example, is a neurotoxicant that can affect brain development in children. Copper and Zinc, although essential for human health, can cause problems when intake is either too low or too high. Understanding the concentration levels of these metals in the environment can help to mitigate the risks associated with exposure.

Ecosystem Health: Heavy metals can have harmful effects on wildlife and can alter the functioning of ecosystems. They can bioaccumulate in organisms, leading to toxic effects that ripple through the food chain. Hence, assessing their levels in the environment is crucial for protecting biodiversity.

Regulatory Standards: The research can inform the development and implementation of environmental regulations and guidelines for heavy metals. By identifying areas with high concentrations of these elements, policymakers can devise strategies to mitigate pollution and ensure industrial compliance with environmental standards.

Industrial Practices: The results can influence industrial practices by identifying sectors or processes that contribute significantly to heavy metal pollution. This can lead to the development of cleaner production methods, promoting sustainable industrial practices.

Future Research: Lastly, this study can serve as a basis for future research, expanding our understanding of heavy metal pollution and its effects on human health and the environment. It can inspire further studies investigating the sources, distribution, and impacts of these pollutants, or exploring novel methods for their removal or reduction.

1.2 Purpose of the Study

The primary purpose of this research is to provide a comprehensive evaluation of the concentration levels of three heavy toxic elements, namely, Zinc (Zn), Lead (Pb), and Copper (Cu), within selected environments. By undertaking detailed investigations into their prevalence in different mediums such as soil, water, and air, we aim to establish an empirical understanding of their distribution and concentration levels. Beyond mere detection, the study also endeavors to identify potential sources of these heavy metals, encompassing industrial, agricultural, or residential origins. Unraveling the pathways through which these elements infiltrate the environment forms a significant part of this objective.

Furthermore, we seek to evaluate the potential health risks and environmental repercussions associated with these detected levels of Zn, Pb, and Cu. This facet of the research necessitates a critical examination of the existing scientific literature to correlate our findings with the documented health and ecological effects of these heavy metals. Lastly, we aim to utilize the results of our study to inform policy and practice. By providing accurate and up-to-date data on the environmental presence of these heavy metals, our research can serve as a catalyst for the formulation of effective pollution control measures and responsible industrial practices. This research, therefore, holds significant potential for contributing to the broader goals of environmental conservation and public health protection.

II. OBJECTIVES OF THE STUDY

1. To quantify the concentration levels of Zn, Pb, and Cu in selected environments using appropriate scientific methods.
2. To identify potential anthropogenic sources (industrial, agricultural, or residential) contributing to the elevated concentration levels of these heavy metals in the environment.
3. To evaluate the potential health risks associated with exposure to these elevated concentration levels of Zn, Pb, and Cu.
4. To assess the ecological impact of these heavy metals, particularly their effects on biodiversity and ecosystem function.
5. To contribute to the existing body of scientific knowledge about heavy metal pollution and its impacts on human health and the environment.

III. LITERATURE REVIEW

A study by Saha and Zaman (2013) investigated the concentration levels of heavy metals, including Zinc, Lead, and Copper, in agricultural soils in India. The researchers found that industrial activities and the use of metal-based pesticides contributed significantly to the increased levels of these metals in the soil.

In a similar vein, Ali et al. (2014) conducted a comprehensive study on the heavy metal pollution in surface water in developing countries. The research emphasized that the improper disposal of industrial waste was a leading source of water pollution, with high concentrations of Zn, Pb, and Cu found in water bodies near industrial areas.

Another important study by Keshavarzi et al. (2015) on heavy metal contamination in street dust in Iran demonstrated a strong correlation between traffic volume, use of leaded gasoline, and high levels of Pb and Cu in street dust.

A more recent study by Wang et al. (2021) explored heavy metal pollution in urban soils in China. Their findings underscored the impact of urbanization and industrialization on the elevated levels of heavy metals in urban environments.

These studies illustrate the diverse sources of heavy metal pollution and underscore the need for regular monitoring and effective mitigation strategies to manage the environmental and health risks posed by these toxic elements.Long-term monitoring studies are limited, especially those that evaluate changes in heavy metal concentrations over time. This gap makes it challenging to understand trends and predict future scenarios of heavy metal pollution.

IV. METHOD AND MATERIAL

Study Sites Selection: Our study will encompass multiple sites, both urban and rural, which are known to have varied industrial, agricultural, or residential activities. These sites will be selected to cover a diverse range of environments and potential contamination sources.

Sample Collection:
Samples from the selected sites will be collected in three main categories: soil, water, and air. Soil samples will be collected from different depths using a soil corer. Water samples will be collected from surface water bodies such as rivers, lakes, and ponds, as well as groundwater sources. Air samples will be collected using highvolume air samplers.

Heavy Metals Analysis:
The concentration levels of Zinc, Lead, and Copper in the collected samples will be analyzed using atomic absorption spectroscopy (AAS) or inductively coupled plasma mass spectrometry (ICP-MS), following standard procedures. Prior to analysis, soil and water samples will be appropriately prepared: soil samples will be airdried, ground, and sieved, while water samples will be filtered and acidified.

Data Analysis:
The data obtained from the heavy metals analysis will be statistically analyzed using software like SPSS or R. Descriptive statistics will be used to summarize the data, while inferential statistics (e.g., ANOVA or regression analysis) will be used to determine significant differences in heavy metal concentrations across sites and to identify potential relationships with environmental factors.

Quality Control:

To ensure the reliability of the results, each sample will be analyzed in duplicate, and standard reference materials will be used to validate the analytical methods. Also, blank samples will be processed and analyzed to check for potential contamination during sample preparation and analysis.

V. RESULT AND FINDINGS

The mean concentrations of toxic metals in all tire samples (Tire A, B, C, D, and E) were in the order of Zn > C u > Pb > Sn > Sb > Ni > Cr > As > Cd (Table 1 and Fig. 1). Zn had the highest concentration among the toxic metals, with mean values of 10,128–13,322 mg/kg. Zn showed a relatively small difference (1.4 times) in concentration among tire samples compared with the other toxic metals. The Zn concentration of domestic tires (Tires A, B, and C) was higher than that of imported tires (Tires D and E) and was similar to those of tires used in the UK (9500 mg/kg; Dong et al. 2017) and USA (12,980 mg/kg; Thapalia et al. 2010).

The mean concentrations of Ni (8.81 mg/kg), Sn (46.8 mg/kg), and Sb (23.7 mg/kg) were relatively high in the domestic tires, whereas those of Cr, Cu, Cd, and Pb were higher in the imported products. Tire D had the highest mean concentrations of Cr (9.70 mg/kg) and Cu (770.7 mg/kg), and Tire E had the highest concentrations of Cd (0.68 mg/kg) and Pb (55.4 mg/kg).

The differences in the mean concentrations among all tire samples were 11-fold for Cr, tenfold for Ni and As, 81-fold for Cu, 14-fold for Cd, 30-fold for Sn and Sb, and sixfold for Pb, which were significantly higher than the difference in the Zn concentration. This difference in toxic metal concentrations in tires reflects differences in the raw materials used by different manufacturers. The difference in the mean concentration of toxic metals in tires produced by the same manufacturer (Tire A) were 1.1- (Zn) to 4.0 (Sb)-fold. Among nonexhaust traffic emission sources, brake pads also were 1.1- (Zn) to 4.0 (Sb)-fold. Among non-exhaust traffic emission sources, brake pads also were made by the same manufacturer but there was a large difference in

Table 1 Mean (standard deviation in parentheses) of toxic metal concentrations (mg/kg) in tires from different manufacturers and comparisons with published data

Samples	Cr	Ni	Cu	Zn	As	Cd	Sn	Sb	Pb
Tire-A (*n* = 5)	2.68 (1.08)	8.81 (1.76)	156.7 (59.9)	12,194 (259)	0.36 (0.16)	0.26 (0.04)	46.8 (25.1)	3.6 (2.0)	13.4 (2.5)
Tire-B (*n* = 6)	8.67 (5.97)	5.32 (2.68)	212.1 (144.5)	13,322 (623)	1.12 (0.60)	0.59 (0.42)	10.2 (10.9)	23.7 (11.0)	33.2 (19.4)
Tire-C (*n* = 1)	2.20	7.28	202.0	12,367	0.25	0.14	24.1	1.3	9.5
Tire-D (*n* = 2)	9.70 (2.35)	1.98 (0.01)	770.7 (203.4)	10,128 (395)	2.18 (0.22)	0.46 (0.14)	21.3 (7.6)	1.1 (0.1)	15.9 (0.4)
Tire-E (*n* = 2)	2.49 (0.36)	6.42 (0.01)	11.6 (0.4)	10,032 (31)	0.86 (0.01)	0.68 (0.01)	2.8 (0.02)	2.9 (0.1)	55.4 (0.8)
Tire (Dong et al. 2017)	–	–	36.7	9,500	–	–	–	–	–
Tire (Thapalia et al. 2010)	–	–	–	12,980	–	–	–	–	–
Background soil (unpublished data)	–	–	36.4	96.9	–	–	–	–	33.9
Road dust (< 10 μm) (Jeong and Ra 2021a)	300	75.6	513	3,007	17.0	5.6	–	61.6	480

concentration depending on the product (Jeong et al. 2022), even the same manufacturer may have used different raw materials depending on the tire product or production period.

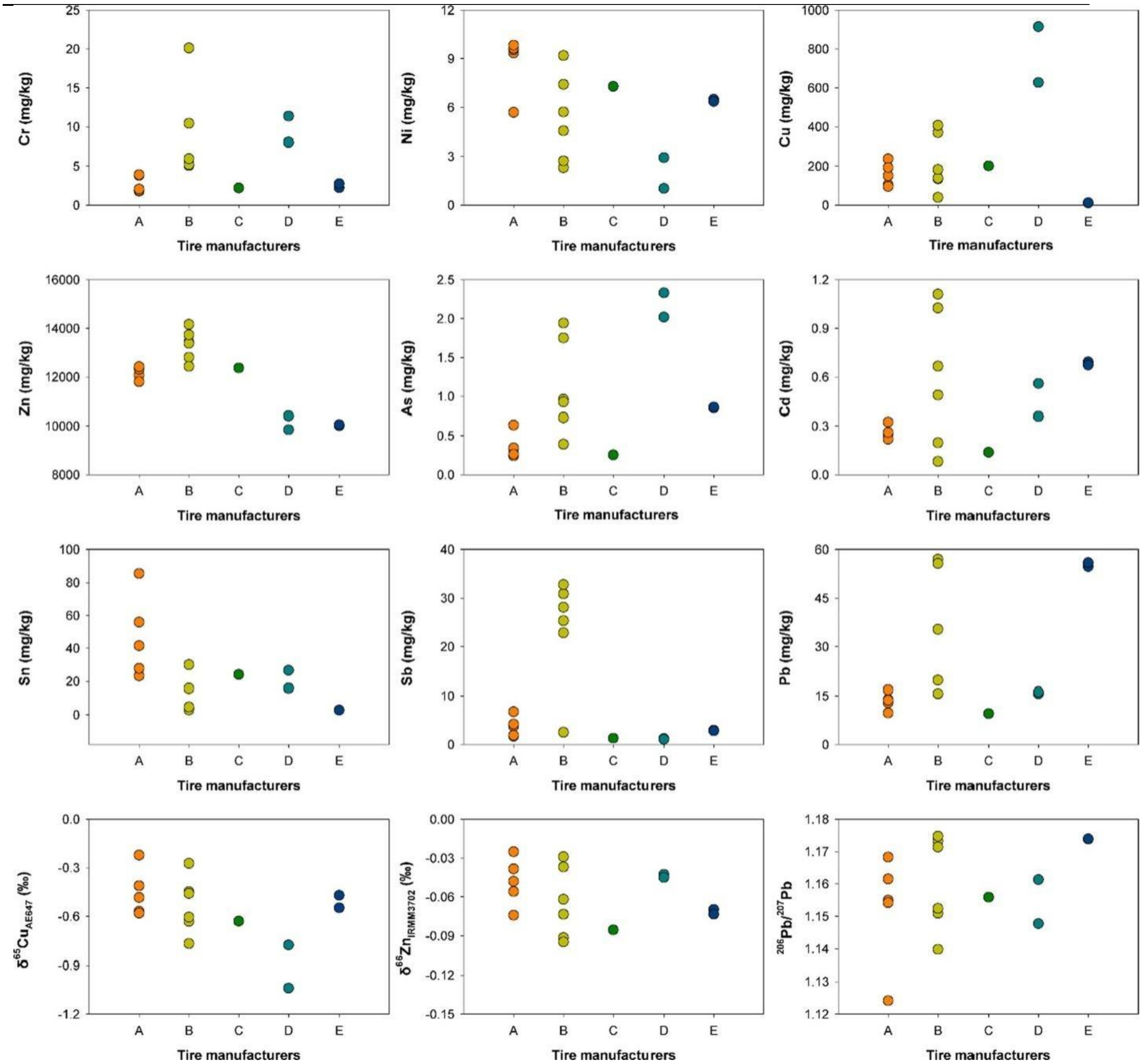

Fig. 1: Comparisons of toxic metal concentrations (mg/kg) and isotopic compositions of Cu, Zn, and Pb among the different tire samples in this study

VI. CONCLUSION

This study provided the toxic metal concentrations and Cu, Zn, and Pb isotopic compositions in tires, which are important sources of metal contamination. Also, this study evaluated how multi-isotope signatures can be useful tools for classifying traffic-related pollutants in urbanenvironments. The Zn concentration was the highest toxic metal concentration in all tire samples. The mean concentrations of Ni, Zn, Sn, and Sb were higher in the domestic tires than imported tires, and there were large differences in metal concentrations depending on the product and manufacturer. These results indicated that multiisotope signatures and their combinations can be useful tools fordiscriminating various non-exhaust traffic sources and background soil. The establishment of such multi-isotope data will play an important role in estimating the relative contributions of metal pollution in environments and managing the potential sources from non-exhaust traffic-related emissions.

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