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Assessment of the Heavy Metal Contaminations of Roadside Soil in Aizawl, Mizoram (India): An In-Depth Analysis Utilising Advanced Scientific Methodologies

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Abstract: The study was conducted to evaluate the heavy metal contamination levels in the roadside soil of Aizawl, Mizoram (India). Twelve sites were sampled monthly from August 2020 to July 2021, and concentrations of copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) were analyzed using atomic absorption spectrometer. The concentrations of heavy metals at the twelve studied sites varied widely from 0.43-1.06, 20.54-21.21, 2.69-3.41, 0.25-0.54, 0.31-0.49 and 1.35-1.77 for Cu, Fe, Mn, Ni, Pb, and Zn respectively. Pollution assessment tools such as the pollution load index, geo-accumulation index, and enrichment factor indicated moderate pollution levels. The study also observed fluctuations in the contamination levels due to the monsoon rainfall and the COVID-19 pandemic lockdown. Principal component analysis identified vehicular emissions, industrial activities, and atmospheric deposition as the potential sources of heavy metal contamination, with varying patterns observed at each site. While the observed heavy metal concentrations generally met permissible limits, the elevated levels suggested anthropogenic influences. It is crucial to continuously monitor and manage heavy metal contamination to mitigate potential health risks associated with heavy metal exposure.

Key words: Heavy metals, roadside soil, pollution, Aizawl, pollution load index, geo-accumulation index, enrichment factor, principal component analysis.

Introduction

Roadside soil is one of the environments that is most vulnerable to heavy metal pollution. The deposition of heavy metals from vehicle emissions, brake and tire wear, and other anthropogenic activities can lead to an increase in the concentration of heavy metals in roadside soil. Heavy metal pollution has become a global issue in recent years, with numerous negative effects on human health (Briffa et al., 2020). With rapid development, intensive anthropogenic activities have resulted in a significant number of pollutants being discharged into the urban environment. Intense anthropogenic activities with a large number of heavy metal sources and high pollution density are more common in cities than in urban regions, causing significant health concerns for humans (Yan et al., 2018).

Earlier, soil contamination was not considered as serious as air and water pollution because soil contamination has a wider range and is more difficult

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to control and manage than air and water pollution (Ashraf et al., 2014). However, several studies on the concentration, distribution, and sources of heavy metals in roadside soils have been conducted in recent years revealing the current trends of soil contamination in developing countries. As a result, addressing soil contamination from heavy metals in roadside areas has become a hot topic of environmental concern worldwide (Su et al., 2014). Roadside soil serves as an important reservoir for pollution from various sources and can easily come into contact with pedestrians and people living near roads, either through suspended dust or direct contact (Mafuyai et al., 2015).

Many recent studies have assessed heavy metal concentrations in roadside soil due to the escalating industrialisation, urbanisation, and transportation activities. Anthropogenic influences significantly impact metal levels in roadside soils, with road transportation identified as a major source of heavy metal pollution and a key player in trace metal biochemical cycles. This study, the first of its kind in Mizoram, focusses on evaluating Cu, Fe, Mn, Ni, Pb, and Zn concentrations in the roadside soil of Aizawl City, aiming to identify the level of contamination and their sources.

Materials and Methods

Study Area

Aizawl, the capital of Mizoram state in northeastern India, is situated on steep hilly terrain at an elevation of 974 meters above sea level. Roads are constructed by cutting through the steep slopes. The cityscape is characterised by narrow and small roads winding through the hilly landscape, often surrounded by buildings. Although there is no large factory in Aizawl and its vicinity, the city is expected to have significant pollution levels, given its high human population density, and is the vibrant center of administrative and economic activities in the state.

Sample Collection and Analysis

The sampling sites are situated between 21º56´N and 23º75´N latitudes and include important road intersections and national highways (Figure 1). The hilly landscape and buildings constructed very close to the narrow roads on both sides inhibit the collection of roadside soils at different distances from *the edge of the main road. Nevertheless, roadside soil s*amples were collected at the roadside *within 2 m of the road edge at the designated 12 sampling sites, collecting* three replications every month. A total of 432 samples were collected from August 2020 to July 2021. The collected roadside soil was placed in a plastic bag and taken to the laboratory. The acid digestion method was employed for sample digestion, and the heavy metal analysis was done by using atomic absorption spectroscopy (AAS, AA-7000F). Metal contamination was avoided as far as possible throughout the sampling and digestion procedures.

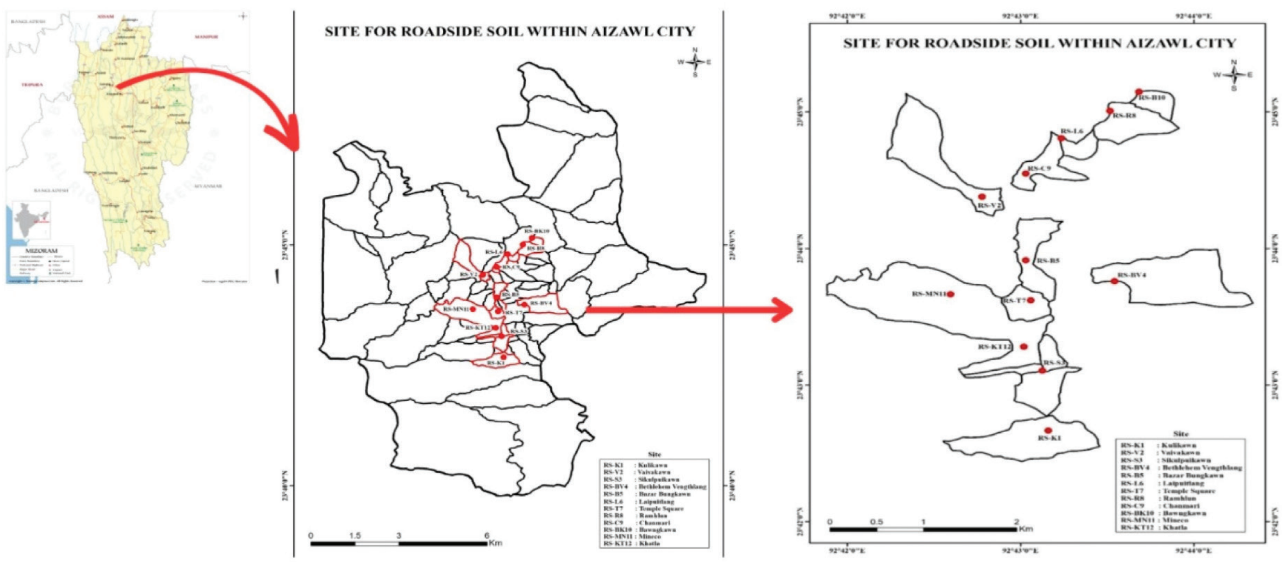


Figure 1: Distribution of sampling sites and location of the study area (Aizawl city).

Pollution Indicators

The pollution index can be used to provide a relative ranking of contamination levels. On the other hand, geochemical approaches, including the geo-accumulation index, pollution load index, enrichment factor, and principal component analysis, can be employed to assess the pollution status and to estimate the impact of anthropogenic activities (Lee et al., 2006).

Enrichment Factor (EF)

To quantify the degree of heavy metal enrichment and estimate the relative contribution of each metal generated from natural and anthropogenic activities, an EF approach was used (Yan et al., 2018). The EF is defined mathematically as:

$$EF_i = (C_i/C_R)_{soil} / (C_i/C_R)_{background}$$

where EF_i is the enrichment factor of trace metal, Ci is the metal concentration of metal in the sample, and CR is the concentration of the reference metal. An EF value of <1.5 indicates that the metal was obtained primarily from the parent material. A larger EF indicates that anthropogenic loading contributes more than natural resources (Yan et al., 2018).

Geo-Accumulation Index (I_{geo})

The I_{geo} is a geochemical criterion for evaluating pollution levels and has been used since the late 1960s. It can be calculated using:

$$I_{geo} = \log_2 (C_n/1.5B_n)$$

where C_n is the measured concentration of metal n in soils or sediments and B_n is the geochemical background value of the corresponding metal.

Pollution Load Index (PLI)

The PLI of the metals was calculated according to the following formula,

$$PLI = (CF_1 \text{ x } CF_2 \text{ ---- x } CF_n)^{1/n}$$

where CF is the concentration of a specific heavy element in the soil sample and n is the number of heavy metals (Lu et al., 2014).

Statistical Analysis

Statistical analysis was performed with the statistical software package SPSS version 22.0 (IBM, Chicago, IL). Identification of the possible sources of heavy metals was performed using principal component analysis (PCA) (Wen et al., 2017).

Results and Discussion

The mean concentrations of heavy metals in roadside soil samples collected from Aizawl City are shown in Table 1. Heavy metals such as Cu, Fe, Mn, Ni, Pb, and Zn at the twelve studied sites varied widely from 0.43-1.06, 20.54-21.21, 2.69-3.41, 0.25-0.54, 0.31-0.49 and 1.35-1.77, respectively, showing that the mean concentrations of heavy metals at all the selected sites within Aizawl city were mostly higher than their

Table 1: Summary of the mean heavy metal concentrations in Aizawl City, Mizoram (in ppm)

Site	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*	*Zn*
RS-K1	0.53	21.20	3.15	0.54	0.49	1.61
RS-V2	0.48	20.96	2.82	0.31	0.29	1.53
RS-S3	0.73	20.83	3.06	0.34	0.40	1.55
RS-BV4	0.72	21.21	3.24	0.38	0.49	1.49
RS-B5	0.96	20.82	2.97	0.25	0.36	1.65
RS-L6	0.61	20.91	2.81	0.25	0.31	1.55
RS-T7	0.94	20.76	3.41	0.31	0.49	1.58
RS-R8	0.57	20.54	2.69	0.34	0.44	1.55
RS-C9	1.06	20.70	2.80	0.26	0.33	1.77
RS-BK10	0.67	20.90	2.77	0.36	0.36	1.60
RS -MN11	0.43	20.74	2.89	0.43	0.32	1.35
RS-KT12	0.70	20.87	2.96	0.34	0.39	1.57
ABVs in Aizawl	0.41	13.27	1.95	0.13	0.15	0.87
China soil guidelines	100	-	-	50	300	250
Canada soil guidelines	64	-	-	50	140	200

corresponding average background values (ABVs). Fe exhibited the highest concentration (20.54 to 21.21 ppm) suggesting a strong association with vehicle pollutants (Skorbiłowicz et al., 2021), followed by Mn (2.69-3.41 ppm).

The distribution of heavy metals in roadside soil samples fluctuated in all twelve sites. Various activities, such as industries, traffic, and human activities, all contribute to metal contamination (Rødland et al., 2023). However, during the monsoon season, Pb concentrations rise at numerous locations, indicating that rainfall washes away building paints, resulting in greater Pb levels (Turner & Lewis, 2018). In the post-monsoon, metal concentration rises in areas with high anthropogenic and traffic activities. I_{geo} and PLI show moderate pollution levels for the studied metals. EF index indicates moderate to high pollution, with no data on extremely contaminated or very polluted classes as shown in Table 2.

Pollution Assessment of Roadside Soil Metals Using Geochemical Indicators

Figure 2 shows boxplots illustrating the monthly PLI values for heavy metals in Aizawl City from August 2020 to July 2021. Throughout the sampling period, Cu displayed the greatest variability, except in the months of May and July 2021. Conversely, Fe consistently exhibited low variability each month. Moreover, the levels of metals such as Mn, Pb, and Zn fluctuated across the different months. High variability indicates significant fluctuations or changes in PLI values from one month to another. The heightened variability of Cu throughout most of the months suggests notable variations in copper concentrations in the study area over the specified period, potentially influenced by factors such as land use patterns, environmental conditions, human activities, or natural processes (Chen et al., 2015).

The comparison of mean heavy metal concentrations across twelve sites during the pre-monsoon, monsoon, and post-monsoon seasons in Graph 1 revealed higher PLI values for Pb and Zn at most sites. Table 2(b) showed that PLI values indicated primarily low to moderate pollution levels for all heavy metals, suggesting anthropogenic influence with varying impacts. The EF indices in Figure 3 demonstrated average EFs for Cu, Fe, Mn, Ni, Pb, and Zn at 3.49, 1.55, 1.23, 2.19, 3.98, and 4.67, respectively. These values reflected varying degrees of enrichment relative to natural background levels, with Cu, Pb, and Zn exceeding the threshold of

Table 2: The percentage of class distribution for pollution assessment of heavy metals in Aizawl roadside soils using (a) I_{geo}, (b) PLI, and (c) EF

Class	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*	*Zn*
(a)	-	-	-	16.67%	-	-
Uncontaminated	75%	100%	100%	58.33%	58.33%	58.33%
Uncontaminated to moderately contaminated	25%	-	-	55%	41.67%	41.67%
Moderately contaminated	-	-	-	-	-	-
Moderate to heavily contaminated	-	-	-	-	-	-
Heavily contaminated	-	-	-	-	-	-
Extremely contaminated	-	-	-	-	-	-
(b)						
Low pollution	8.33%	8.33%	-	8.33%	-	-
Moderate pollution	666.67%	75%	100%	91.67%	75%	75%
High pollution	25%	16.67%	-	-	25%	25%
Very High pollution	-	-	-	-	-	-
(c)						
Depletion to minimal pollution	16.67%	66.67%	100%	50%	41.67%	8.33%
Moderate pollution	58.33%	33.33%	-	50%	41.67%	41.67%
Significant pollution	25%	-	-	-	16.66%	50%
Very strong pollution	-	-	-	-	-	-
Extreme pollution	-	-	-	-	-	-

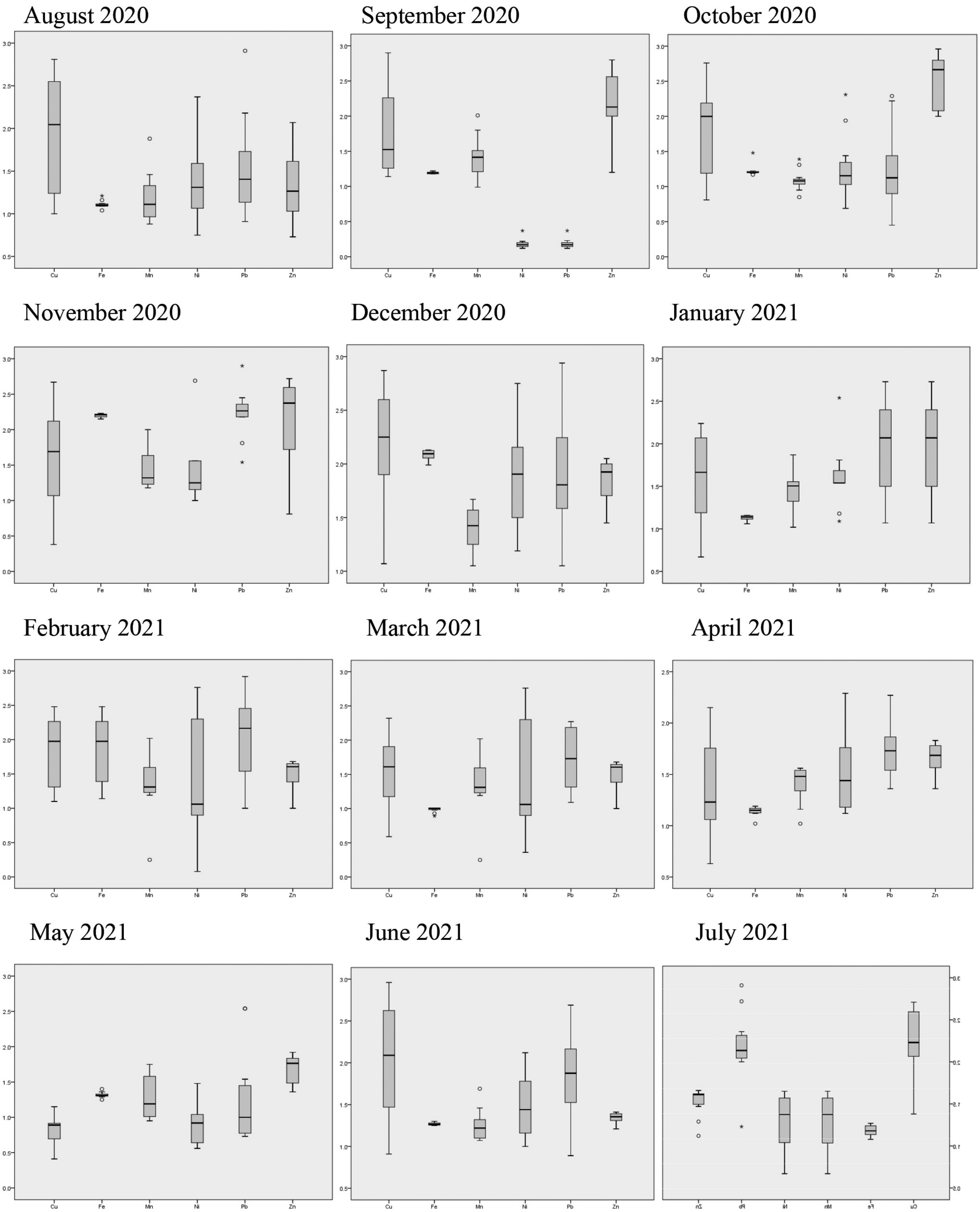


Figure 2: Boxplots of the PLI of heavy metal in the roadside soils of Aizawl from August 2020 to July 2021.

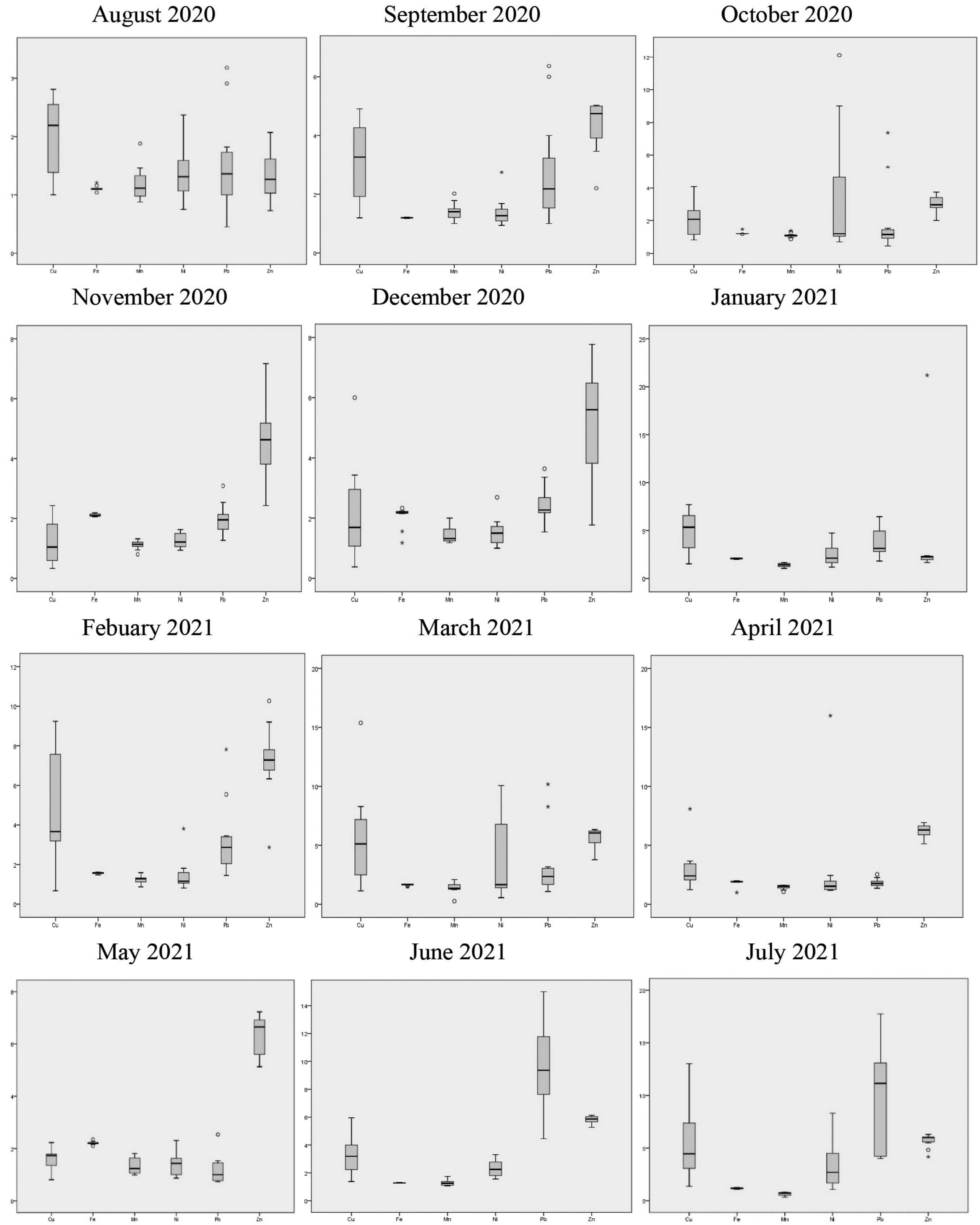


Figure 3: Boxplots of the EFs of heavy metals in roadside soil in Aizawl from August 2020 to July 2021.

1.5, indicating the notable anthropogenic influence on metal concentrations in roadside soil (Chen et al., 2015).

Graph 2 illustrates overlapping metal concentrations across seasons, with Pb showing the highest enrichment post-monsoon at RS-S3. Table 2(c) indicates minimal to moderate pollution levels based on the Enrichment Factor (EF) for heavy metals. Aizawl's roadside soil exceeded ABVs, with Cu dominating the contamination.

Table 3: Matrix of principal component analysis loadings for trace metal concentrations in roadside soil

Site	*Metals*	*PC1*	*PC2*	*PC3*	*Site*	*Metals*	*PC1*	*PC2*	*PC3*
RS-K1	Cu	0.943	-	-	RS-T7	Ni	0.971	-	-
	Ni	0.897	-	-		Cu	0.951	-	-
	Pb	0.788	-	-		Fe	-	0.901	-
	Mn	0.654	-	-		Zn	-	0.879	-
	Fe	-	0.938	-		Mn	-	-	0.872
	Zn	-	0.878	-		Pb	-	-	0.863
% of Variance explain		47.739	36.856	-	% of Variance explain		41.429	31.185	19.295
RS-V2	Cu	0.818	-	-	RS-R8	Zn	0.850	-	-
	Ni	0.801	-	-		Cu	0.839	-	-
	Pb	0.721	-	-		Mn	0.717	-	-
	Fe	-	0.868	-		Ni	0.634	-	-
	Zn	-	0.863	-		Pb	-	0.826	-
	Mn	-	0.643	-		Fe	-	0.779	-
% of Variance explain		43.727	28.542		% of Variance explain		43.019	27.292	-
RS-S3	Zn	0.767	-	-	RS-C9	Fe	0.871	-	-
	Cu	0.719	-	-		Zn	0.869	-	-
	Pb	0.695	-	-		Cu	0.717	-	-
	Mn	-	0.792	-		Mn	-	0.776	-
	Ni	-	0.702	-		Pb	-	0.687	-
	Fe	-	0.686	-		Ni	-	0.685	-
% of Variance explain		43.061	21.875		% of Variance explain		45.345	20.262	-
RS-BV4	Zn	0.937	-	-	RS-BK10	Ni	0.965	-	-
	Cu	0.845	-	-		Pb	0.798	-	-
	Pb	-0.666	-	0.600		Cu	0.674	-	-
	Mn	-	0.805	-		Fe	-	0.878	-
	Ni	-	0.804	-		Mn	-	0.798	-
	Fe	-	-	0.879		Zn	-	0.760	-
% of Variance explain		37.286	26.811	17.785	% of Variance explain		42.215	36.808	-
RS-B55	Pb	0.955	-	-	RS-MN11	Zn	0.861	-	-
	Ni	0.910	-	-		Ni	0.807	-	-
	Cu	0.805	-	-		Cu	0.619	-	-
	Mn	-0.804	-	-		Pb	-	0.843	-
	Zn	-	0.912	-		Mn	-	0.752	-
	Fe	-	0.799	-		Fe	-	-0.617	-
% of Variance explain		54.383	26.765	-	% of Variance explain		40.0882	28.968	-
RS-L6	Ni	0.814	-	-	RS-KT12	Ni	0.969	-	-
	Pb	0.753	-	-		Pb	0.947	-	-
	Cu	0.721	-	-		Fe	-	0.956	-
	Fe	-	0.933	-		Zn	-	0.922	-
	Zn	-	0.715	-		Cu	-	-	0.874
	Mn	-	-	0.934		Mn	-	-	0.656
% of Variance explain		72.269	43.727	47.738	% of Variance explain		38.664	32.845	16.682

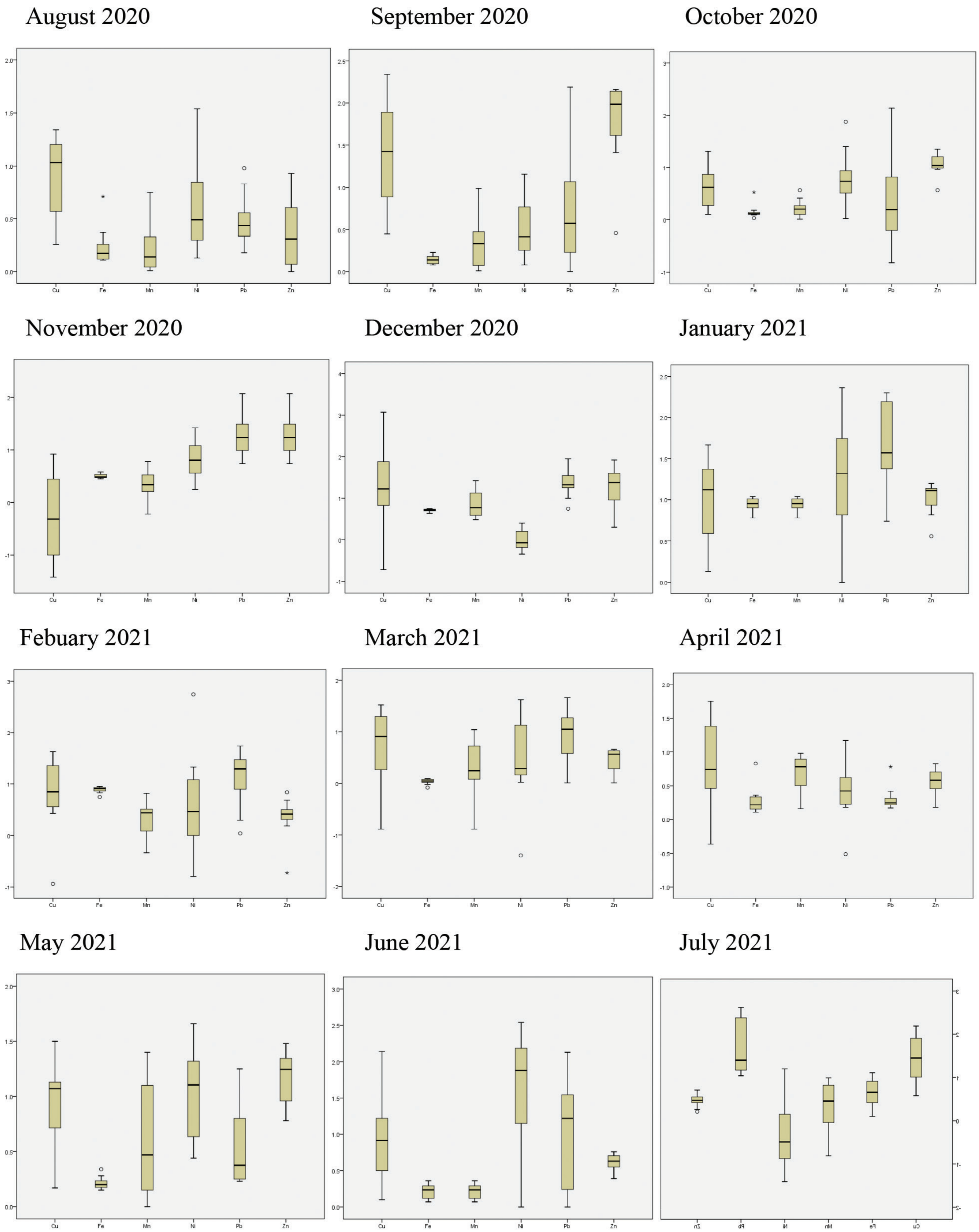
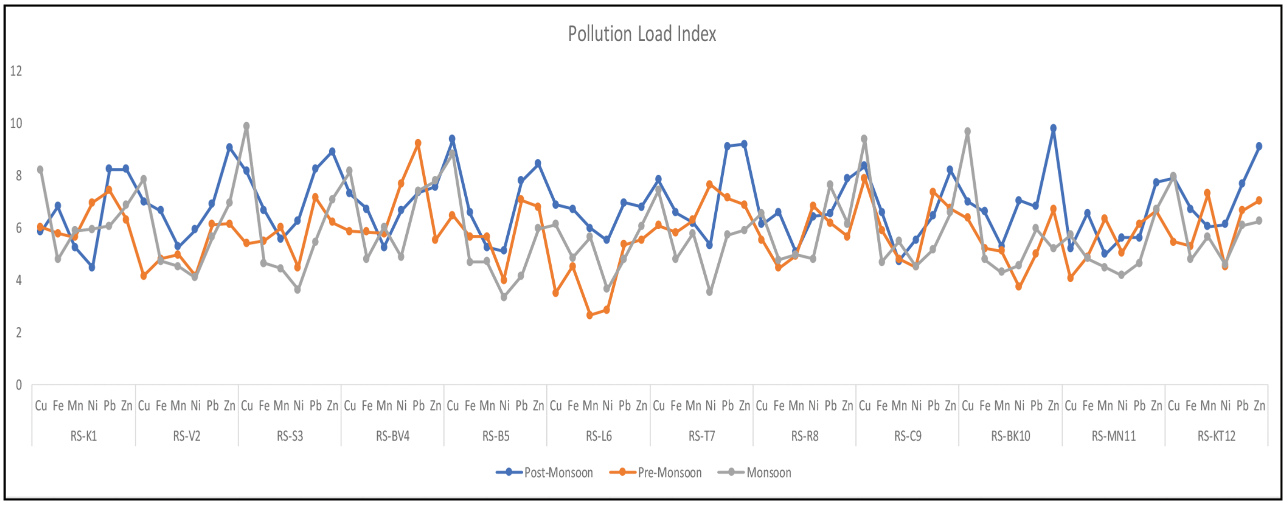
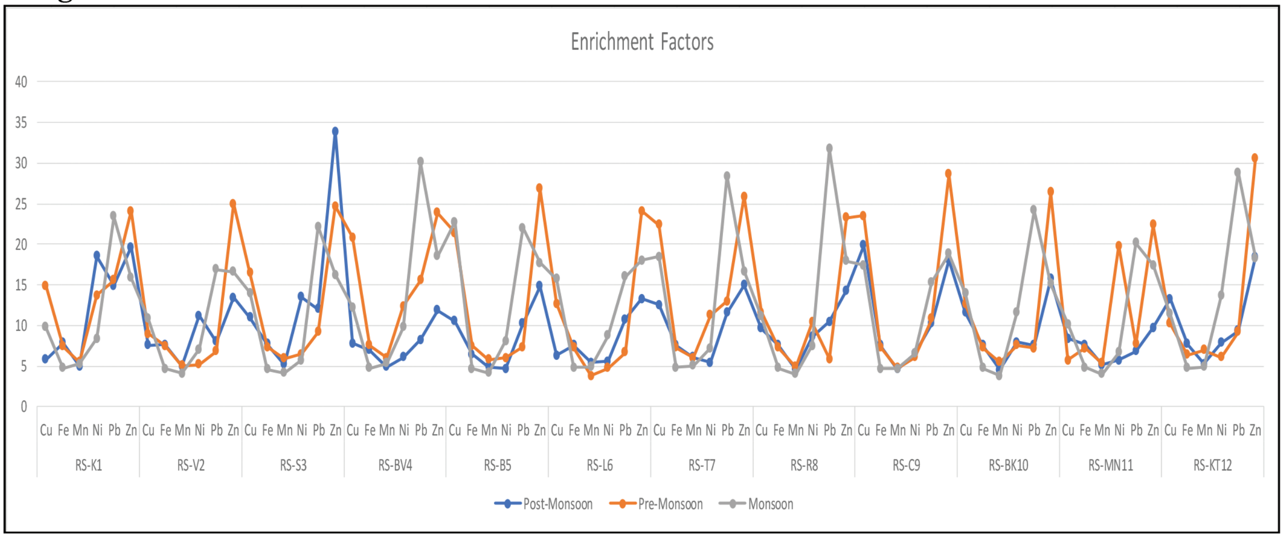


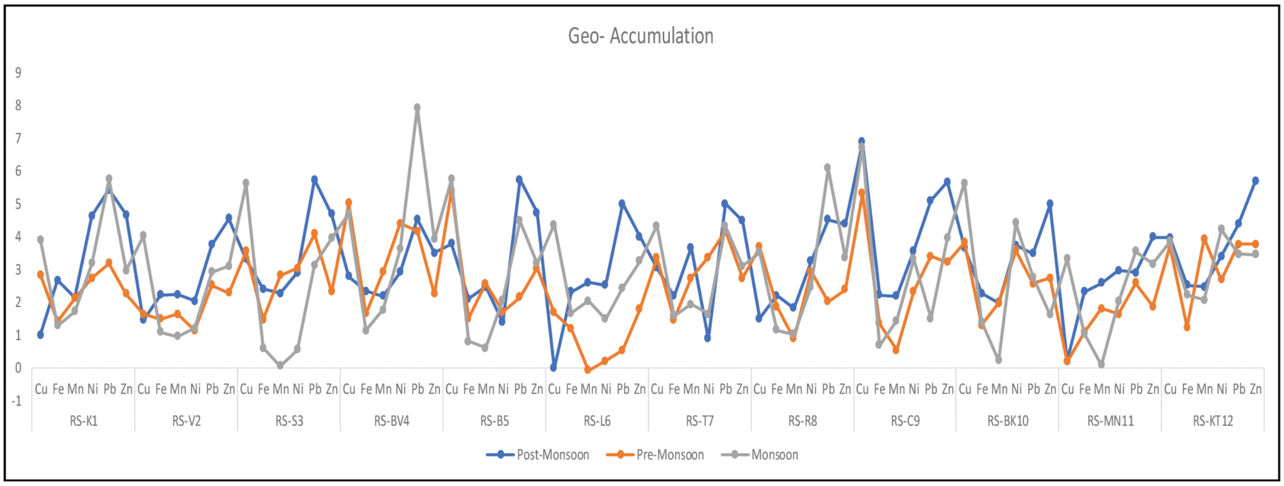
Figure 4: Boxplots of the I_{geo} values for heavy metals in Aizawl roadside soils from August 2020 to July 2021.



Graph 1: Influence of monsoon in the variation of heavy metals concentrations on selected sites using PLI



Graph 2: Influence of monsoon in the variation of heavy metals concentrations on selected sites using EFs.



Graph 3: Influence of monsoon in the variation in heavy metals concentrations on selected sites using the I_{geo}.

I_{geo} analysis in Graph 3 highlighted higher concentrations during the monsoon, notably in RS-BV4. Most metals fell into the uncontaminated to moderately contaminated category, as indicated in Table 2(a). The box plot in Figure 4 illustrates the heavy metal pollution levels, highlighting the impact of monsoon rainfall and variations at specific locations.

Identification of Pollution Sources

Principal component analysis (PCA) classified metals into groups based on their concentrations. Two and three rotated principal components (PCs) were derived, collectively explaining dataset variability. At RS-K1, trace metals were separated into two components, accounting for 84.590% of data variability. Component 1, led by copper, nickel, lead, and magnesium, explained 47.738% of the variance, while Component 2, featuring iron and zinc, explained 36.856%. Similar patterns were observed at other sites, with distinct metal dominance in specific components. For instance, RS-T7 displayed three components, collectively explaining 91.910% of the variability. Each component reveals unique metal patterns, with vehicular emissions influencing Cu and Ni, and industrial activities potentially impacting Fe and Zn (Åström et al., 2017). The concentration of Pb suggests a possible link to traffic-related activities, emphasising the diverse anthropogenic sources contributing to pollution in various roadside soils (Kaur et al., 2022) (Table 3). The study focusses on quantifying heavy metals in roadside soils, with vehicular emissions as the main source of lead pollution. Contamination factor and PCA are used to assess metal pollution, emphasising Zn, Pb, and Cu from traffic-related sources. Elevated metal contamination in street dust is impacted by vehicle traffic and industrial operations, with lead, zinc, and copper detected in fine particles (Lee et al., 2021).

The study conducted in Aizawl City identified specific sites with varying concentrations of heavy metals in roadside soils. Among these sites, RS-C9 exhibited the highest Cu concentration (1.06 ppm) which could be influenced by intense human and vehicular activities, while RS-MN11 showed the lowest Cu contamination (0.43 ppm). For Fe, RS-BV4 had the highest mean concentration (21.21 ppm), which could be attributed to heavy traffic, and human activity (Skorbiłowicz et al., 2021). Mn levels were the highest at RS-T7 (3.41 ppm), possibly due to road maintenance activities nearby. Ni concentrations were the highest at RS-K1 (0.54 ppm) and RS-MN11 (0.43 ppm), reflecting the impact of vehicle emissions and intense human activities. Pb concentrations varied widely with RS-BV4, RS-K1, and RS-T7, identified as the most contaminated sites. RS-V2, where the sampling site has a steep slope, and RS-L6, which is situated at the hilltop with a higher elevation, had lower Pb levels. Zn concentrations were the highest at RS-C9 (1.77 ppm), probably due to railing construction works nearby and vehicular emissions. These findings highlight the spatial variability of heavy metal contamination in roadside soils across different sites in Aizawl City, emphasising the need for continued monitoring efforts to mitigate environmental and health risks associated with heavy metal pollution.

The heavy metal concentrations in the roadside soil samples collected within Aizawl City ranged from 0.1 to 5ppm for the selected metals as represented in Table 1. The distribution of heavy metals on roadside soils fluctuates over time, which could be because all of these studies were conducted during the global COVID-19 pandemic, when the Mizoram government frequently imposed total lockdowns, resulting in a decrease in public movement. The SED (2020) report indicated that the average number of LMV movements per day in October 2020 ranges between 1000 to 1120, while bus and truck movements average approximately 100 per day, which can have a significant impact on metal concentrations on roadside soil. Heavy metal concentrations were greater at most of the sites from November 2020 to January 2021, possibly because the movement of people and vehicles increased in a raid form as the government lifted the lockdown during these months. On the other hand, it is festival season and there is higher traffic, with approximately 2000 two-wheeler movements alone per day observed in most locations.

Conclusion

This study conducted in Aizawl, the capital city of Mizoram (India), offers profound insights into scenarios of heavy metals in roadside soil. Focussing on six pivotal heavy metals such as Cu, Fe, Mn, Ni, Pb, and Zn that are commonly associated with vehicular emissions, road-related activities, anthropogenic activities, and industrial processes. The study unveiled varying levels of heavy metal contamination, and the highest of the mean metal concentrations observed are in the order: Fe>Mn >Zn>Cu>Ni>Pb. Elevated concentrations of heavy metals were observed at specific sites such as RS-K1, RS-BV4, and RS-C9, underscoring the spatial variability influenced by metal types and their respective sources. Temporal fluctuations in heavy metal concentrations, influenced by vehicular and human activities like festivals and by the lockdown due to the COVID-19 pandemic, were observed. Pollution assessments using indicators like PLI, EF, and I_{geo} indicated moderate to high pollution levels in roadside soil, mainly from anthropogenic sources. PCA identified distinct metal dominance patterns, with vehicular emissions, industrial activities, and urbanization as primary contributors. Close monitoring of heavy metals in roadside soils is crucial for environmental protection and public health.

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