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Original article

Assessment of the Heavy Metal Contents in Air Samples Collected from the Area Extended Between Albayda and Alquba Cities (Libya)

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Abstract
This study aimed to assess the concentrations of heavy metals, including copper (Cu), iron (Fe), lead (Pb), and zinc (Zn), in air samples collected from five areas in northeastern Libya: Al-Qubbah, Al-Abraq, Lamluda, Shahat, and Al-Bayda. Samples were taken during both summer and winter, with exposure periods of two types: daily and weekly, to examine spatial and seasonal variations and identify potential sources of atmospheric metal pollution. Results revealed significant differences in copper and zinc concentrations between seasons and between study sites. Copper showed a significant increase in winter, especially in Lamluda, where the weekly concentration reached 0.045 µg/ml compared to 0.031 µg/ml in summer (P = 0.0234). Conversely, a decrease was observed in Al-Abraq, from 0.0235 µg/ml (summer, day 1) to 0.019 µg/ml in winter. Zinc showed the greatest seasonal variation, with particularly high levels in winter. In the Abraq area, zinc concentrations increased from 0.167 µg/ml in summer to 0.497 µg/ml in winter (P = 0.0127). Similarly, Lamlouda recorded a sharp increase, reaching 0.460 µg/ml in winter versus 0.029 µg/ml in summer. In contrast, iron and lead were largely undetectable except for a few samples, preventing any robust comparative analysis of these two elements. Spatially, Lamlouda, Abraq, and Al Bayda showed generally higher average concentrations of copper and zinc, which may be related to population density, traffic, and some local industrial activities. These results highlight the need for regular environmental monitoring of heavy metals in the air, especially during winter.
Keywords: Heavy Metals, Air, Pollution, Green Mountain, Libya.

Introduction

In a world characterized by rapid industrialization and increasing urbanization, air quality has become a critical issue for public health and environmental sustainability. Air pollution encompasses a wide range of pollutants, with heavy metals among the most dangerous due to their acute toxicity, chemical stability, and potential for bioaccumulation in organisms [1]. Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) are of particular concern. Lead can severely affect the nervous system, especially in children, while cadmium is associated with kidney and bone disorders, and mercury with significant neurological damage [2]. Other metals, such as nickel (Ni), chromium (Cr), and zinc (Zn), while important in small quantities, become toxic at high concentrations. These substances are associated with various negative effects, including DNA damage, cell disorders, respiratory problems, and skin diseases [3,4]. Copper(Cu), commonly used in industrial processes, can also cause oxidative stress and liver damage when inhaled in excessive amounts [5].

The main sources of atmospheric emissions of these metals include metal smelting, fossil fuel combustion, mining activities, and road traffic. These activities significantly contribute to atmospheric metal pollution, especially in urban and industrial areas [6,7]. The persistence of heavy metals in the environment is also a major risk factor. Once released, they remain active for long periods, accumulating in the air, soil, water, and living organisms. This chronic accumulation disrupts biological processes, even at extremely low concentrations [8]. This study aims to fill this scientific gap by assessing the concentrations of heavy metals (copper, iron, lead, and zinc) in the air surrounding these five Libyan regions. Samples were collected during summer and winter, taking into account two exposure periods (one day and one week), to study the seasonal and spatial variations of these elements.

Methods

Study Area

The study area is located in the Green Mountain region in northeastern Libya, one of the highest and most diverse regions in the country. It is known for its temperate climate and mountainous landscapes, as well as its rich flora and agricultural activities. The study focuses on five main regions: Al-Qubbah, Al-Abraq, Lamluda, Shahat, and Al-Bayda, which vary in elevation above sea level and geographical location within the Green Mountain. Figure (1) shows a map of the Green Mountain in Libya, showing the study areas, and Table 1 shows the coordinates of the study areas.

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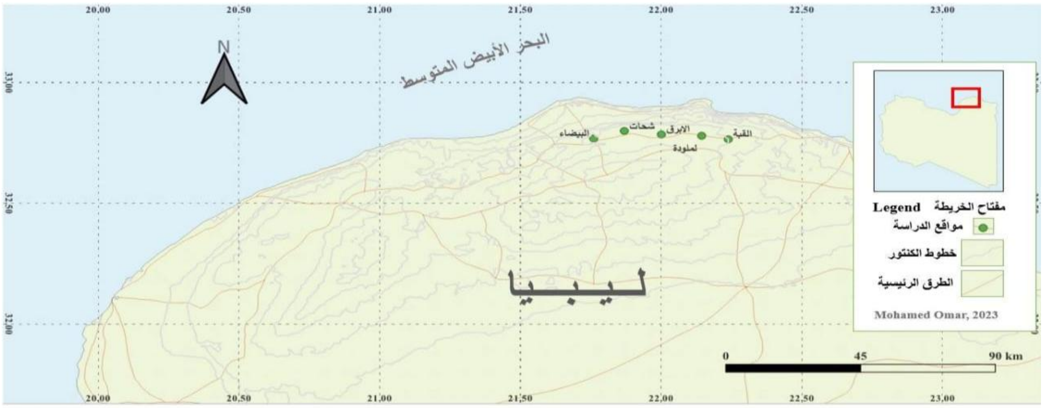

Figure 1. Map showing the study areas.

Table 1. Coordinates of the study areas.

Region	Latitude (North)	Longitude (East)	Altitude (m)
Quba	32.7675	22.2324	332
Al-Abraq	32.7864	21.964	476
Lmlouda	32.792	21.7391	625
Shahat	32.8282	21.8622	600
Al-Bayda	32.7627	21.7551	621

Study Design
The study was designed as a comparative temporal and regional analysis of atmospheric concentrations of copper, iron, lead, and zinc. Samples were collected in five different regions during the summer and winter seasons. For each region, two sets of samples were taken: one day after exposure and the other one week later. This setup allowed for the assessment of seasonal and short-term temporal variations in metal concentrations across different geographic locations.

Data Collection
The study focused on collecting airborne heavy metal particles (copper, lead, iron, and zinc). Samples were collected using fabric-based sedimentation techniques, which allowed airborne particles to settle on the fabric surface over a specified period.

Sampling Methods
Air samples were collected using a simple and effective method. The process involved placing a dry cotton cloth or towel on the building's roof, where it remained exposed to the atmosphere for a specified period. After the exposure period, each cloth was carefully collected and treated individually. Each cloth was soaked in distilled water for one hour to extract the particles that had adhered to it. The resulting water was then collected and analyzed to determine the concentrations of airborne heavy metals, such as copper, iron, lead, and zinc.
Two sampling periods were used: Day 1 sample: A cloth was placed and left exposed for one day to collect airborne particles. Week 1 sample: A second cloth was placed and left exposed for one week to collect particles over a longer period. This sampling method was repeated in all five regions during the summer and winter seasons. The goal was to allow airborne particles and heavy metals to effectively settle onto the fabric, enabling accurate analysis of the extracted water samples.

Data Analysis
The collected fabric samples were analyzed for concentrations of copper (Cu), iron, lead, and zinc (Zn) using laboratory-based analytical techniques. The fabric was transported to a specialized laboratory, where metal particles were extracted and quantified. Laboratory analysis was performed using standard procedures for detecting and quantifying trace amounts of metals in environmental samples, such as inductively coupled plasma-mass spectrometry (ICP-MS). Results were expressed as micrograms per milliliter (µg/ml) of the metal concentration in the sample. Data collected from the laboratory analysis were then subjected to various statistical tests, including paired t-tests and two-way analysis of variance, to determine whether there were significant differences in metal concentrations based on region, season, and time of exposure.

Results
Table 1 shows the airborne concentrations of copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) (expressed in micrograms/ml) measured by season (summer/winter), exposure duration (one day/one week), and for five

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regions in eastern Libya (Al-Quba, Lamluda, Al-Abraq, Shahat, and Al-Bayda). The results showed that heavy metal concentrations increase in winter, particularly after one week of exposure, confirming the influence of climatic conditions and human activities on metal air pollution. These observations reinforce the importance of implementing emission control measures, particularly in urban areas such as Al-Bayda and Shahat, where population density exposes a greater number of people to the harmful effects of air pollution.

Table 1. Seasonal changes in air concentrations of heavy metals as a function of time.

Seasonal changes		City	Cu (µg/ml)	Fe (µg/ml)	Pb (µg/ml)	Zn (µg/ml)
Summer	Day	Al-Quba	ND	0.021	ND	0.011
		Lamluda	0.02	ND	ND	0.045
		Al-Abraq	0.014	ND	ND	0.119
		Shahat	0.019	ND	ND	0.053
		Al-Bayda	0.012	ND	ND	0.031
	Week	Al-Quba	0.008	ND	ND	0.042
		Lamluda	0.031	ND	0.027	0.029
		Al-Abraq	0.018	ND	ND	0.167
		Shahat	0.011	ND	ND	0.048
		Al-Bayda	0.016	ND	ND	0.028
Winter	Day	Al-Quba	0.019	ND	ND	0.261
		Lamluda	0.023	ND	ND	0.033
		Al-Abraq	0.033	ND	ND	0.414
		Shahat	0.016	ND	ND	0.085
		Al-Bayda	0.019	ND	ND	0.029
	Week	Al-Quba	0.009	ND	ND	0.018
		Lamluda	0.045	0.01	ND	0.46
		Al-Abraq	0.012	ND	0.017	0.497
		Shahat	0.016	ND	ND	0.144
		Al-Bayda	0.02	ND	ND	0.028

In summer, the highest copper (Cu) concentration was recorded in the Qubbah area (0.020 µg/ml), while the lowest concentration was measured in the Shahat area (0.012 µg/ml). This variability may be attributed to differences in human activities and traffic in these areas. The higher concentrations observed in Qubbah, a more urbanized city, confirm the findings of some studies [9] which indicated that urban areas record higher copper concentrations due to vehicle brake and tire wear, as well as industrial emissions. In comparison, the lower concentrations in Shahat may be related to lower population density and less industrial activity.

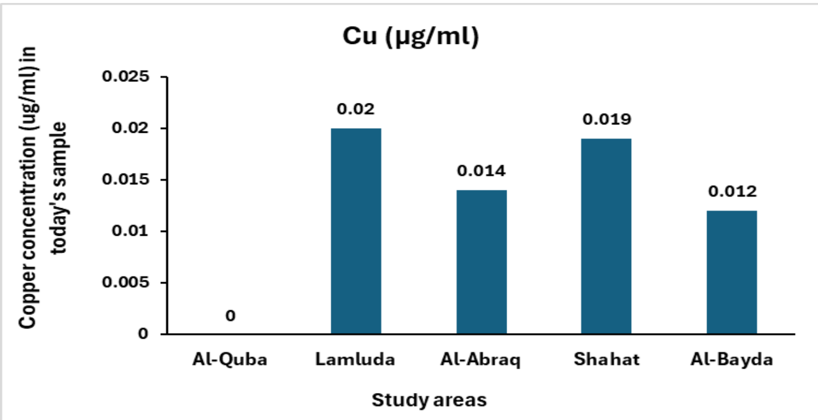

Figure 2. Copper concentration (µg/ml) of the sample during the day in the summer.

After a week of exposure in the summer, the maximum copper concentration was detected in the Dome area (0.031 µg/mL), while the lowest value was recorded in the Bayda area (0.016 µg/mL). This accumulation over a week illustrates the gradual deposition of metal particles in the ambient air, exacerbated by the low rainfall in the summer and the stagnation of pollutants. A study by some studies [10], also showed that urban areas accumulate higher amounts of heavy metals in the air over a long period, due to heavy traffic and continuous industrial emissions.

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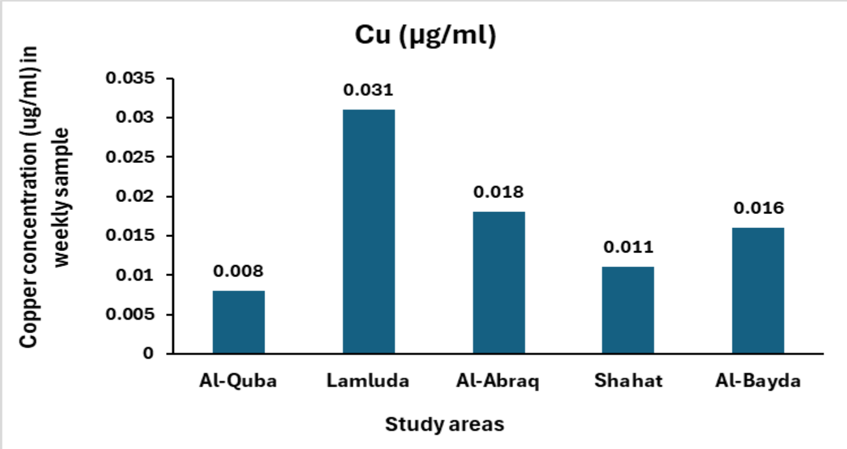

Figure 3. Copper concentration (µg/ml) of the sample of one week in the summer.

In winter, copper concentrations are generally higher than in summer. The highest concentration was measured in the Dome area (0.033 µg/mL), while the lowest concentration was detected in the Shahat area (0.019 µg/mL). The seasonal rise in copper levels can be attributed to the intensification of fossil fuel combustion for heating, as highlighted by [11], who observed a significant increase in suspended heavy metals during the colder months due to the increased use of coal and other energy sources. This winter elevation also confirms the findings of [12], who confirmed that atmospheric stability and thermal inversions in winter lead to the accumulation of metal pollutants in urban environments.

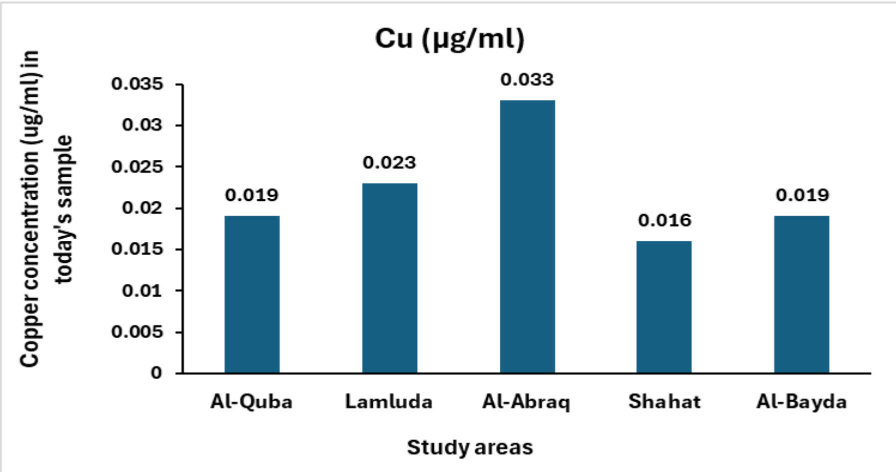

Figure 4. Copper concentration (µg/ml) of the samples during one day in winter.

After one week in winter, the highest copper concentration was detected in the Dome area (0.046 µg/mL), while the lowest value was recorded in the Bayda area (0.020 µg/mL). The significant increase in weekly concentrations compared to daily measurements indicates that heavy metals are not easily dissipated in winter, possibly due to atmospheric conditions that reduce the dispersion of suspended particles. This trend is consistent with the study by study [13], which demonstrated that copper and iron concentrations in the air increase in winter, exacerbating respiratory diseases due to the prolonged accumulation of fine particles.

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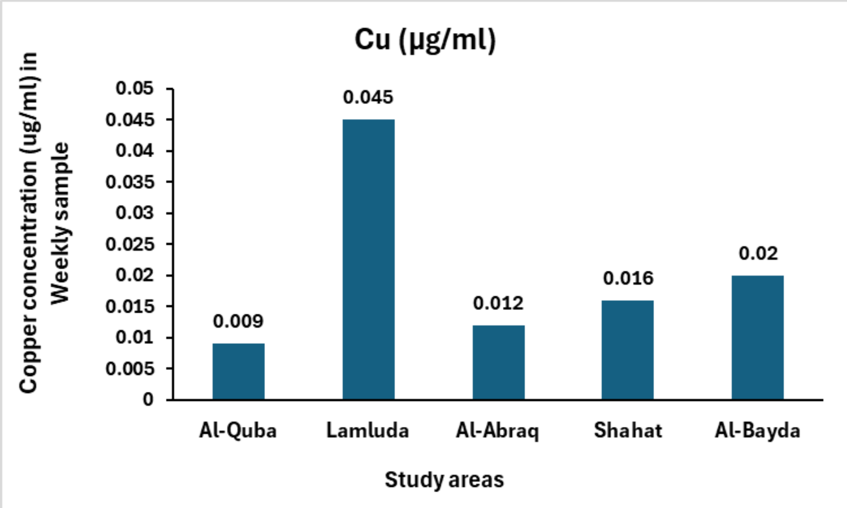

Figure 5. Copper concentration (µg/ml) of one-week sample in winter.

Regarding iron (Fe), the data show a single detection in the summer, at a concentration of 0.021 µg/mL in the dome, while iron was not detected at other sites and during the winter. The absence of iron in the winter is surprising, especially given that some studies, such as the study [14], have observed higher iron concentrations in winter in urban-industrial areas due to coal combustion and industrial emissions. This absence in winter samples may be due to geographic features and local emission sources, which may not be dominated by activities that generate suspended iron. Lead (Pb) was detected only in the summer after one week of exposure, at 0.027 µg/mL in Al-Abraq, while it remained undetectable at all other periods and sites. This low presence may be related to restrictions on the use of lead in fuels and limited industrial emissions in these areas.

A study [15] showed that lead concentrations in urban air are strongly influenced by the proximity of metallurgical industries and vehicle emissions, which explains its limited presence in the samples collected here. Zinc (Zn) concentrations followed a similar trend to copper concentrations, with higher levels recorded in winter. In summer, the highest concentration was measured in Al-Abraq (0.119 µg/mL) and the lowest in Al-Bayda (0.031 µg/mL). This distribution suggests the influence of road traffic and local industrial activity on the presence of atmospheric zinc, as demonstrated in the study by [16], which revealed that urban roads and intersections are hotspots for zinc accumulation due to tire wear and vehicle emissions.

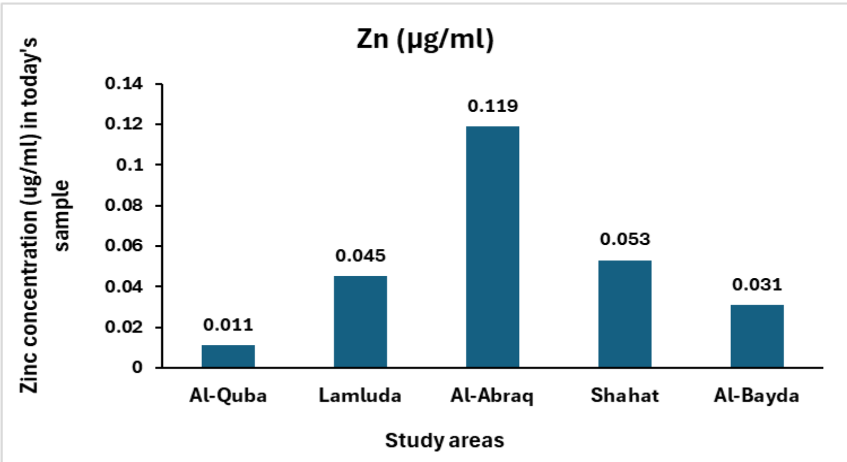

Figure 6. Zinc concentration (µg/ml) of the samples during one day in the summer.

After a week in the summer, the highest zinc concentration was found in the Al-Abraq area (0.167 µg/ml) and the lowest in the Al-Bayda area (0.028 µg/ml). The gradual accumulation of zinc in the air over time may be related to its low variability and gradual deposition in the atmosphere, a phenomenon described by [17], who showed that zinc levels increased in densely populated areas where road traffic was constant.

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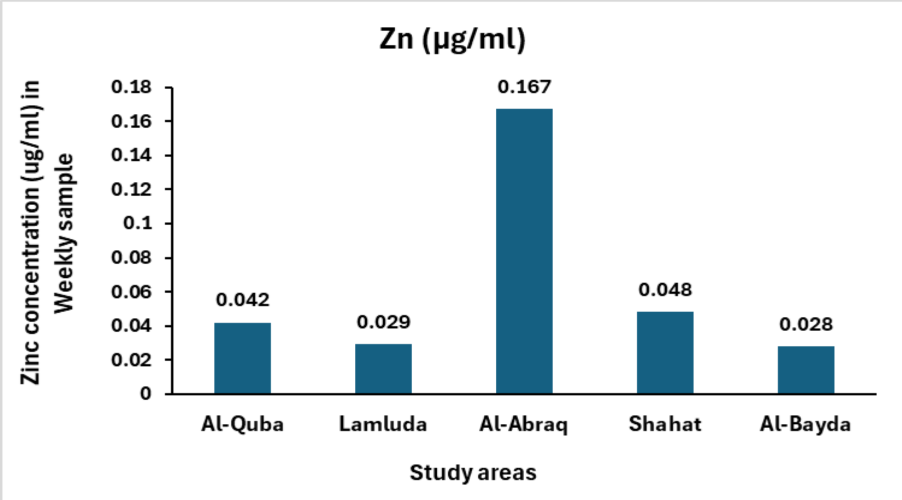

Figure 7. Zinc concentration (µg/ml) of the samples for one week in the summer.

In winter, concentrations rise further, reaching a maximum value of 0.041 µg/ml in Abraq, while the lowest concentration was observed in Shahat (0.029 µg/ml). This increase in levels in winter is consistent with the findings of [18], who demonstrated that suspended zinc levels are higher during the colder months due to increased industrial activities and fossil fuel combustion.

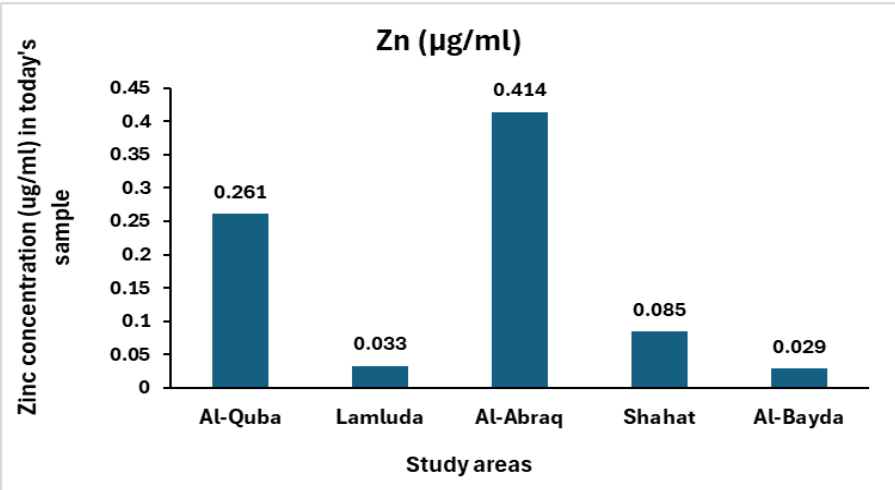

Figure 8. Zinc concentration (µg/ml) of the samples during one day in winter.

After one week in winter, zinc concentrations reached 0.497 µg/ml in Al-Abraq, the highest value observed in the entire data set, while the lowest value remained in Al-Bayda (0.028 µg/ml). This significant increase reflects the combined effect of industrial emissions and adverse weather conditions that reduce particle dispersal. These observations are consistent with the study by [19] which demonstrated that winter climatic conditions favor the accumulation of heavy metals in suspensions, increasing their impact on human health.

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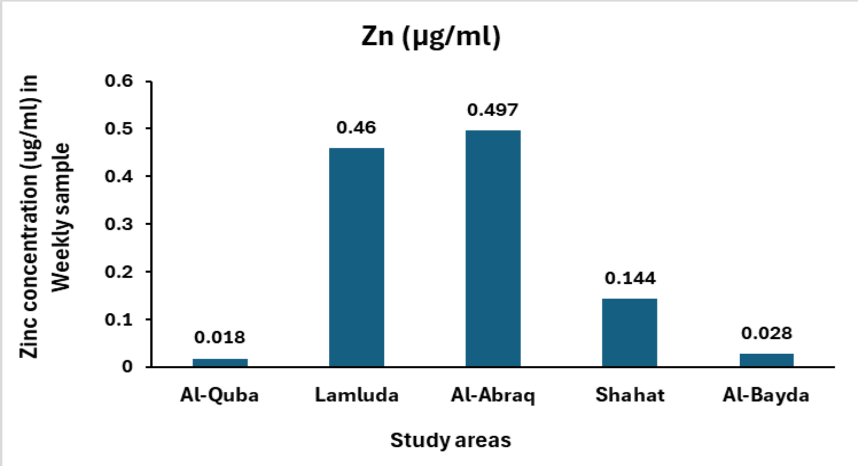

Figure 9. Zinc concentration (µg/ml) of one weekly sample in winter.

Table 2 exhibited the means, standard deviation, and P value of copper (Cu) and zinc (Zn) concentrations as a function of season (summer/winter) and exposure duration (day/week).

Table 2. Comparison of copper (Cu) and zinc (Zn) concentrations between daily and weekly samples according to the season.

Minerals	Season	Time	Mean	Std-Deviation	P-value
Cu (µg/ml)	Summer	day	0.013	0.008	0.497
		Week	0.0168	0.0089	
	Winter	day	0.022	0.0066	0.829
		Week	0.0204	0.0144	
Zn (µg/ml)	Summer	day	0.0518	0.041	0.741
		Week	0.0628	0.059	
	Winter	day	0.1644	0.168	0.629
		Week	0.2294	0.233	

Mean summer copper concentrations show a slight increase between daily (0.013 µg/ml) and weekly (0.0168 µg/ml) measurements, with a low standard deviation, indicating a gradual accumulation of copper in the air over time. However, the P value (0.497) indicates that this increase is not statistically significant, suggesting that the variation may be due to natural variability rather than a persistent pollution source. copper accumulation in urban air is generally influenced by road traffic and industrial processes, but its dispersal is facilitated by favorable summer weather conditions.

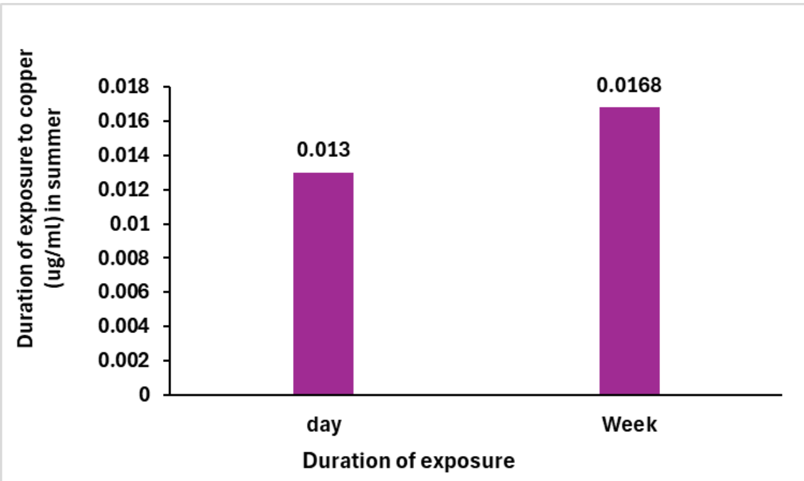

Figure 10. Copper (Cu) concentrations between daily and weekly samples in summer.

In winter, copper concentrations are higher than in summer, reaching 0.022 µg/ml for daily measurements and 0.0204 µg/ml for weekly measurements. In contrast to summer trends, the concentration does not show an increase after one week, possibly due to atmospheric conditions that limit copper diffusion, resulting in stable concentrations over several days. The P value (0.829) indicates that this variation is not statistically significant, suggesting that copper is likely emitted continuously from pollution sources, including fuel combustion for heating. These results confirm the observations of Liu et al. (2019), who showed that copper

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levels increase in winter due to heating-related emissions, but daily variations may be limited by atmospheric stability and thermal reflections.

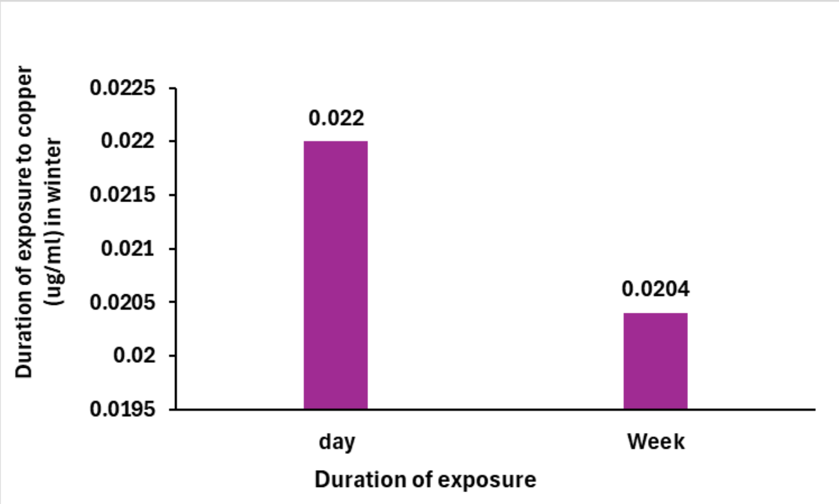

Figure 11. Copper (Cu) concentrations between daily and weekly samples in winter.

Regarding zinc, the daily concentration in summer (0.0518 µg/ml) was lower than the weekly concentration (0.0628 µg/ml), indicating a gradual accumulation of this metal. However, the P value (0.741) also indicates no significant difference between daily and weekly measurements. This observation is consistent with the work of study which demonstrated that zinc is primarily emitted by tire wear and industrial emissions, but can disperse more rapidly in summer due to wind and rainfall [16].

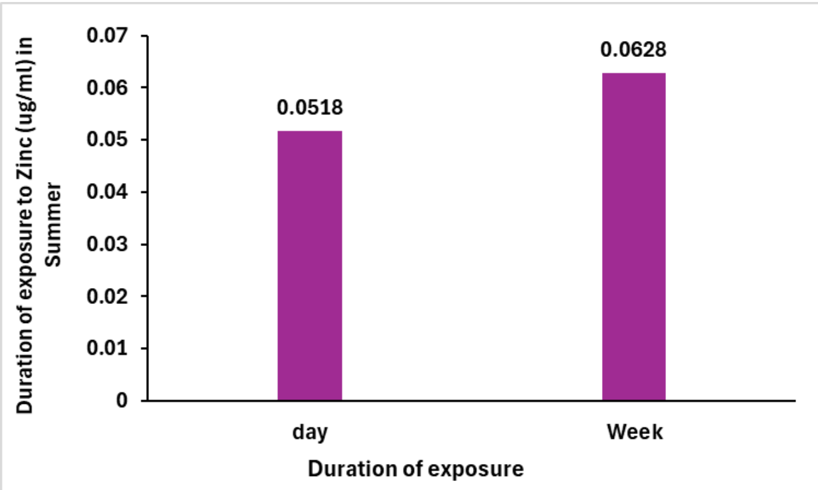

Figure 12. Zinc (Zn) concentrations between daily and weekly samples in winter.

Zinc concentrations in winter showed a significant increase compared to summer, reaching 0.1644 µg/ml for daily measurements and 0.2294 µg/ml for weekly measurements. This increase is significant compared to summer values, confirming that zinc is more present in the air in winter, mainly due to coal combustion and industrial emissions. However, the P value (0.629) indicates that the difference between daily and weekly measurements is not statistically significant, which could be explained by the continuous emission of zinc into the atmosphere without excessive accumulation. This observation confirms the findings of studies that stated that zinc levels increase in winter due to heating activities and the burning of fossil fuels, which contribute to persistent pollution [9].

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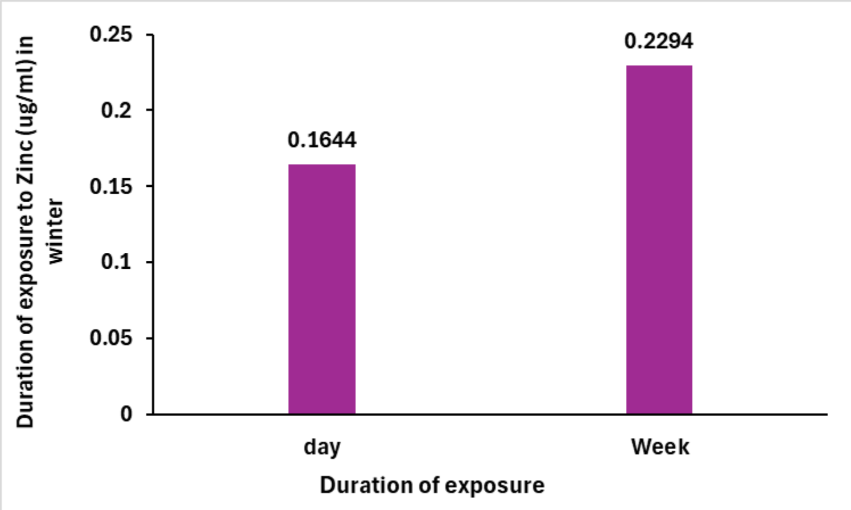

Figure 13. Zinc (Zn) concentrations between daily and weekly samples in winter.

This table shows the means, standard deviations, and P values for copper (Cu) and zinc (Zn) concentrations measured in summer and winter. It highlights the increased concentrations of these metals in winter compared to summer.

Table 5. Comparison of average copper and zinc concentrations in summer and winter

Minerals	Season	Mean	Std-Deviation	P-value
Cu (µg/ml)	Summer	0.0149	0.0076	0.2346
	Winter	0.0212	0.0079	
Zn (µg/ml)	Summer	0.0573	0.0488	0.1279
	Winter	0.1969	0.1641	

Average copper concentrations increased from 0.0149 µg/mL in summer to 0.0212 µg/mL in winter, with a similar standard deviation in both seasons, indicating a moderate but consistent variation. This winter increase reflects increased emissions from anthropogenic sources, including the combustion of fossil fuels for heating, a phenomenon already been observed in a significant increase in heavy metals in winter due to increased coal use [13].

For zinc, the seasonal variation is even more pronounced: the average winter concentration (0.1969 µg/mL) is more than three times higher than the concentration measured in summer (0.0573 µg/mL). This trend confirms the findings of studies that demonstrated that zinc concentrations increase in winter due to industrial emissions and waste burning [11]. This increase may also be influenced by reduced atmospheric dispersion in winter, due to thermal inversions that favor the accumulation of pollutants, as suggested by Al-Shammari (2020). However, the P values for copper (0.2346) and zinc (0.1279) indicate that these differences are not statistically significant, suggesting they may be due to natural variations rather than a dominant human factor. Nevertheless, the observed trend remains consistent with previous studies, demonstrating the influence of seasonal changes on atmospheric metal pollution. Although copper and zinc concentrations were higher in winter, the lack of statistical significance suggests that other factors, such as local weather, emission sources, and particle dispersion, could influence these levels. These findings reinforce the importance of continuous monitoring of air quality, especially in urban and industrial areas where these metals may pose a risk to public health. It was demonstrated that there are respiratory effects of copper- and zinc-rich particulate matter [17].

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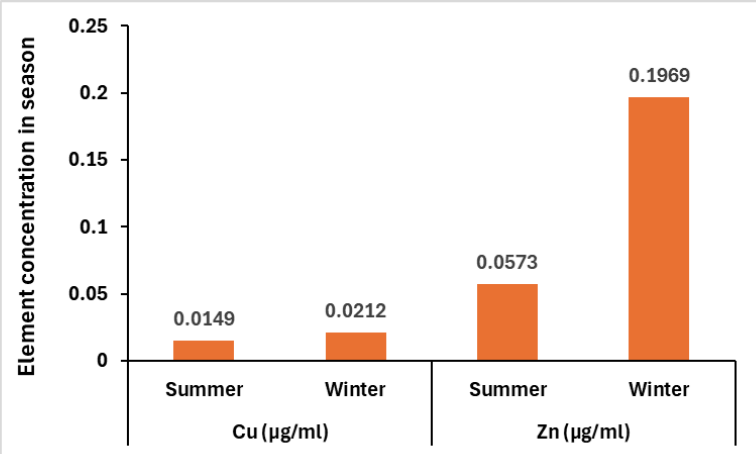

Figure 14. Seasonal changes in the levels of airborne heavy metals (copper and zinc).

Table 6 shows that copper and zinc concentrations vary significantly from one city to another, indicating the influence of local human activities, urban density, and geographical characteristics on air pollution by heavy metals. These results reflect the need to adopt targeted environmental control measures according to the specificities of each region.

Table 6. Average copper and zinc concentrations and standard deviations for each city.

City	Cu (µg/ml)		Zn (µg/ml)	
	Mean	Std-Deviation	Mean	Std-Deviation
Al-Quba	0.009	0.0067	0.083	0.103
Lamluda	0.0298	0.0097	0.142	0.184
Al-Abraq	0.0193	0.0082	0.299	0.160
Shahat	0.0155	0.0029	0.083	0.038
Al-Bayda	0.0168	0.0031	0.029	0.001
P-value	0.0019		0.0091	

Table 6 shows the significant differences in the average concentrations of copper (Cu) and zinc (Zn) measured in five Libyan cities. It is noted that the Lamluda area recorded the highest average copper concentration (0.0298 µg/ml), followed by the Abraq area (0.0193 µg/ml), while the lowest copper concentration was recorded in the Qubbah area (0.009 µg/ml). This variation is statistically significant as demonstrated by the P-value of 0.0019, indicating that geographical location has a real impact on copper levels in the air.

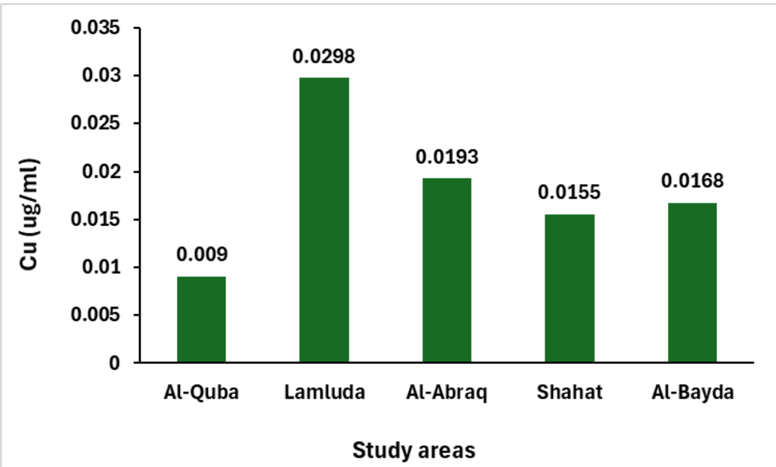

Figure 15. Concentration of copper (Cu) in the various study areas.

Regarding zinc, Al-Abraq clearly has a very high concentration (0.299 µg/ml), which is much higher than other cities, while Al-Bayda shows the lowest value (0.029 µg/ml). A P value of 0.0091 confirms that these differences are also statistically significant.

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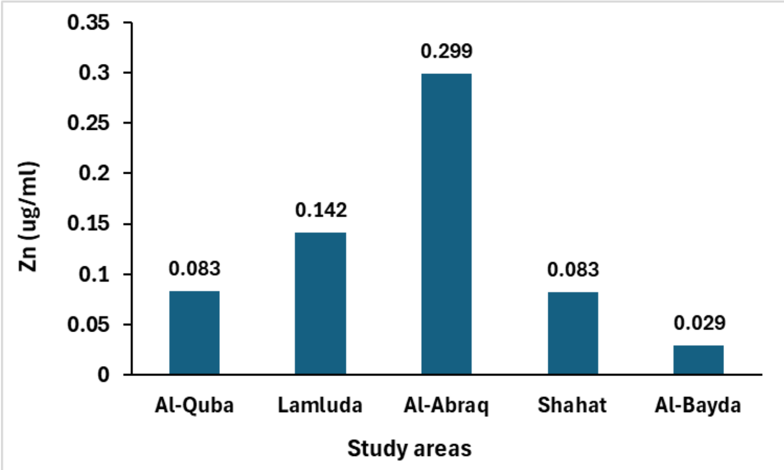

Figure 16. Concentration of zinc (Zn) in the various study areas.

These results can be interpreted in light of previous studies. For example, Marín-Sanleandro et al. (2024) showed that zinc concentrations may be higher in areas close to roads or industrial zones, which may explain the elevated levels in Al-Abraq. Furthermore, the high copper concentration in Lamluda, despite being a rural area, may indicate the presence of specific sources such as artisanal or agricultural activities that use copper-based products, as suggested in similar contexts in Africa [20]. Al-Bayda, despite being the most populous city, has lower concentrations of both metals, which may be linked to better dispersal of contaminants, perhaps due to more favorable geographic or climatic conditions, by the observations of some studies on the influence of wind and terrain on the dispersal of heavy metals [19].

Discussion

According to the results recorded in this there are amounts of some heavy metals detected in the air samples of the area under investigation, these metals included Fe, Pb, Cu, and Zn. Where their concentrations were ranged between (ND-0.021), (ND-0.027), (0.009- 0.045), and (0.011-0.497 µg/ml), respectively.

The main varieties of heavy metals in the environmental samples included different sources as fossil fuel combustion, industry, human activities, and/or pollution coming from the population community. These activities significantly contribute to atmospheric metal pollution, especially in urban and industrial areas. The persistence of heavy metals in the environment is also a major risk factor. Once released, they remain active for long periods, accumulating in the air. In eastern Libya, cities such as Al-Bayda, Shahat, Al-Abraq, Lamluda, and Al-Qubbah are experiencing rapid transformations associated with urban expansion, transportation growth, and industrial development, leading to a significant increase in the airborne load of heavy metals. However, local data on the concentration, distribution, and sources of these metals remain limited, making it difficult to assess risks and implement appropriate mitigation strategies. In light of this situation, our findings in this study are in harmony with some that concluded that the main sources of these elements in the environmental samples are mainly due to the direct influence of human activities [21-27].

Conclusion

The results of this study highlighted significant spatial and temporal variation in heavy metal concentrations in the ambient air of the studied areas in northeastern Libya. Copper and zinc concentrations were generally higher during the winter, due to reduced atmospheric dispersion and increased anthropogenic sources such as domestic heating and road traffic. The highest zinc levels were recorded in Al-Abraq and Lamluda, sometimes exceeding 0.45 µg/ml, reflecting a potential environmental risk in these areas. Lead and iron were largely undetectable, but their occasional presence in some samples underscores the need for ongoing monitoring. The analysis also showed that areas with high population density or industrial activity, such as Shahat and Al-Bayda, are more likely to have varying and sometimes high concentrations of some metals. These results confirm that air pollution by heavy metals poses a public health problem, especially in rapidly developing areas. It is therefore essential to establish a regular environmental monitoring system to reduce emissions from transportation and industrial activities and promote sustainable solutions to maintain air quality and protect local populations. This research provides an important basis for future environmental studies in Libya and similar regions.

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الملخص

ان الهدف الرئيسي من هذه الدراسة هو تقدير تراكيز بعض العناصر وهي النحاس والحديد والرصاص والزنك في عينات تم تجميعها من المنطقة الممتدة ما بين مدينتي البيضاء والقبة بليبيا ، وشملت كلا من مناطق شحات والابرق ولملودة بالإضافة الي البيضاء والقبة وذلك خلال فترات ممتدة من يوم وحتى اسبوع، وخلال فصلي الشتاء والصيف ، وقد بينت نتائج الدراسة ان تراكيز العناصر قيد الدراسة كانت كالاتي : 0.045 µg/ml و 0.031 µg/ml وذلك خلال فصلي الشتاء والصيف على التوالي، بينما كانت تراكيز الزنك خلال الشتاء 0.497 µg/ml ، بينما في الصيف كانت 0.167 µg/ml ، وكانت تراكيز الحديد والرصاص قليلة وغير محسوسة في معظم مواقع الدراسة ، وقد اعزت الدراسة ان وجود العناصر في العينات قيد الدراسة بسبب وجود بعض الانشطة البشرية او الي بسبب عواد المركبات الالية التي تمر بمواقع الدراسة.

الكلمات المفتاحية. العناصر الثقيلة، الجو، تلوث، الجبل الاخضر، ليبيا