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AIR QUALITY IN JELGAVA: IMPACTS OF INDUSTRIAL OPERATIONS

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Abstract
Air pollution in urban areas remains a critical challenge, particularly in densely populated cities. Industrial activities contribute significantly to air quality deterioration through the emission of heavy metals and trace elements that pose risks to human health and the environment. This study investigates the spatial variability of air pollution in Jelgava, Latvia, with a focus on areas impacted by industrial emissions. Snow samples were collected across the city to monitor air pollution, with analyses targeting metals such as lead, arsenic, nickel, copper, zinc, and cadmium. Using cluster analysis, regions were categorized by pollution intensity, uncovering distinct spatial patterns. Results indicate that industrial zones and areas near major roadways exhibit significantly elevated concentrations of toxic metals, often exceeding regulatory thresholds. Seasonal variations, particularly increased emissions from winter heating, were found to exacerbate pollution levels. These findings underscore the importance of continuous monitoring, stricter regulations, and targeted pollution control measures to mitigate health risks and environmental impacts. The study emphasizes the need to integrate pollution management into urban planning and public health policies, providing a foundation for informed decision-making and sustainable urban development. By identifying pollution hotspots, this research provides a foundation for informed decision-making to minimize health risks and promote sustainable urban development in Jelgava. Additionally, the use of snow sampling as a cost-effective and practical method for monitoring airborne pollutants offers valuable insights for other cities facing similar challenges.
Keywords: air pollution, heavy metals, urban monitoring, emissions.

Introduction

Air pollution from industrial activities is a critical environmental and public health concern, particularly in urban areas where industrial facilities are located near residential populations (Zhang et al., 2022). The emission of trace metals, including lead (Pb), cadmium (Cd), nickel (Ni), zinc (Zn), arsenic (As) and copper (Cu), from industrial processes can have severe health implications, as these metals are known to be toxic even at low concentrations. Chronic exposure to airborne heavy metals has been linked to respiratory diseases, cardiovascular issues, neurological disorders, and developmental impairments, especially in vulnerable populations such as children and the elderly (Kampa & Castanas, 2008). According to recent studies, particulate matter (PM2.5) is often enriched with these trace metals, enhancing their ability to penetrate deep into the respiratory system and increasing associated health risks (Guo et al., 2022).

In urban centres worldwide, industrial sources such as metal smelting, waste incineration, and chemical manufacturing contribute significantly to the atmospheric load of heavy metals (Janta et al., 2020). A study conducted in China's zinc smelting districts, for example, demonstrated high concentrations of heavy metals in air and soil, emphasizing the health risks posed to nearby communities (Zheng et al., 2010). Similarly, urban centres in Europe have also reported elevated levels of heavy metals near industrial zones, highlighting the global nature of this environmental issue (Ahmed et al., 2021). In Latvia, as in other European Union member states, air quality is regulated by strict limits on pollutant concentrations to protect public health. However, data on trace metal concentrations in ambient air are limited, particularly in cities with significant industrial activity like Jelgava. Jelgava, an industrial hub in Latvia, hosts a variety of industrial operations that potentially contribute to heavy metal emissions, affecting air quality and posing health risks to its residents. Past research has highlighted the challenges in monitoring and managing trace metal emissions, given the complex interactions of industrial, transportation, and seasonal sources (Martiņsone, 2011).

The aim of this study is to analyse the spatial distribution of trace metal concentrations in Jelgava city using cluster analysis to identify zones with varying pollution levels. By employing snow sampling as a proxy for air pollution, the study will assess concentrations of heavy metals and examine the influence of proximity to industrial sources on these concentrations. This approach will provide a detailed understanding of pollution hotspots in the city, enabling the identification of areas at higher risk of exposure. The findings will contribute to the development of targeted pollution mitigation strategies and inform future monitoring and regulatory policies in Jelgava.

Materials and Methods

Jelgava is one of the largest cities in Latvia and serves as a significant centre of the Zemgale region. The city is located on the banks of the Lielupe River, approximately 40 kilometres from the capital, Riga. Jelgava hosts a range of industrial enterprises with key activities concentrated in metal processing, chemical production, and related sectors. Samples were collected in December 2020. A total of 59 monitoring points were selected within the city boundaries, along with one control point in a rural area southwest of Jelgava. Sample collection took place following the first snowfall. The snowfall period, which covered sample accumulation, lasted five days. Samples were collected 5 meters from the road edge. Snow depths at the monitoring points ranged from 7 to 15 cm (SLLC 'Latvian Environment, Geology and Meteorology Centre', 2025).

A steel ring with an inner diameter of 25 cm was used to define the sampling area, ensuring standardized and replicable sampling. The ring was fixed vertically onto the undisturbed snow. Snow samples were collected from the ring into sterile plastic containers using disposable dust-free nitrile gloves and transported to the laboratory. In the laboratory, the collected snow samples were melted and acidified with nitric acid (HNO_3) to a 1% concentration (m/m). After 72 hours, the samples were filtered and analysed.

The samples were analysed by means of an inductively coupled plasma mass spectrometer (ICP-MS, 'Agilent 8900 ICP-QQQ'). The elements analysed included nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), and lead (Pb). For calibration, an ICP-MS standard solution (10 $mg \cdot L^{-1}$, High Purity Standards, ICP-MS-68 A, NIST SRM 3100) was used. The calibration curve was established for concentrations ranging from 0.1 $\mu g \cdot L^{-1}$ to 100 $\mu g \cdot L^{-1}$. A 10 $\mu g \cdot L^{-1}$ internal standard solution containing Bi, Ge, In, Sc, Tb, Y, and Li was used for internal system stability control. Measurements were performed in MS/MS configuration using helium as the collision gas (flow rate of 5 $mL \cdot min^{-1}$) (Grinfelde et al., 2021).

Results and Discussion

Metals – Ni, Cu, Zn, As, Cd, and Pb – are all common pollutants associated with industrial processes.

Figure 1

Sample locations based on clusters

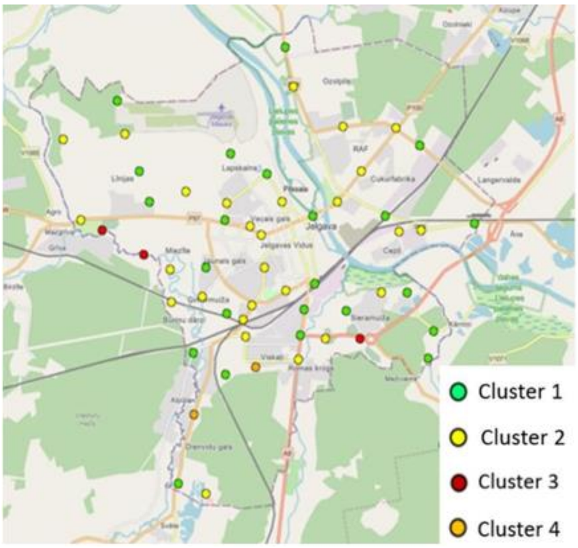


Figure 1 shows a map of Jelgava city with sampling locations categorized by cluster. The clusters are represented by differently coloured markers.

Cluster 1 (green): predominantly low contamination levels, spread across various parts of the city. Most of these points are located on the outskirts and suburban areas, suggesting lower pollution levels due to distance from industrial sources

Cluster 2 (yellow): represents moderate contamination. These points are spread across the city, with some concentration near central and moderately industrialized ar eas, indicating moderate exposure to pollution.

Cluster 3 (red): indicates the highest contamination levels. The red points are concentrated near industrial zones and major roadways, suggesting significant pollution due to proximity to emissions from industrial activities.

Cluster 4 (yellow–red): shows specific metals unique to certain industries, scattered but located near industrial sources. This cluster helps in identifying contamination that may be specific to certain industrial processes.

Figure 2

Ni concentration in each cluster

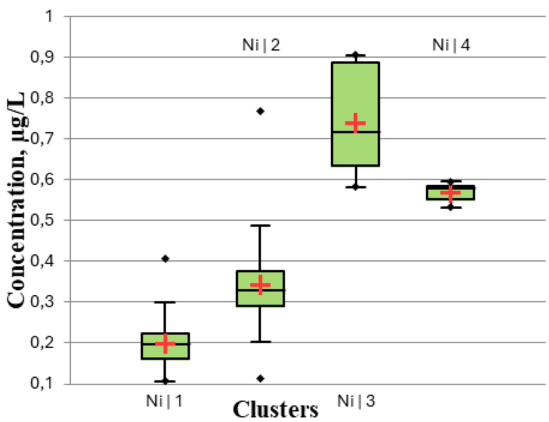


Figure 2 illustrates Ni concentrations in different clusters. It shows that Cluster 3 has the highest nickel concentrations and the greatest variation, with Cluster 2 exhibiting a significantly higher range compared to other clusters. Clusters 2 and 4 demonstrate notably lower Ni concentrations, while Cluster 1 shows the lowest concentrations but still contains some variations. The box plots indicate that Ni levels vary among these clusters, possibly due to industrial activities or proximity to specific pollution sources.

Figure 3 shows the concentration of Cu in each cluster. Cluster 3 has the highest concentration, with values reaching up to 14 $\mu g \cdot L^{-1}$, indicating a significant pollution source in that area. Clusters 2 and 4 show a moderate concentration, while Cluster 1 has lower values. These variations in Cu concentrations suggest different levels of industrial or environmental influence across the clusters, with Cluster 3 likely being the most impacted by Cu emissions.

Figure 4 shows the concentrations of Zn across the clusters. Cluster 3 has the highest concentration of Zn, with a range extending up to approximately 30 μg · L^{-1}, suggesting a significant pollution source in this area. Cluster 2 exhibits moderate Zn concentrations, with values ranging between approximately 5 and 20 μg · L^{-1}. Cluster 1 has very low Zn concentrations compared to others, indicating minimal environmental or industrial impact. Cluster 4 also shows low Zn concentrations, with very narrow variability, likely reflecting a negligible source of Zn pollution. These patterns may correspond to varying levels of industrial activity, traffic density, or natural environmental factors influencing each cluster.

Figure 3
Cu concentration in each cluster

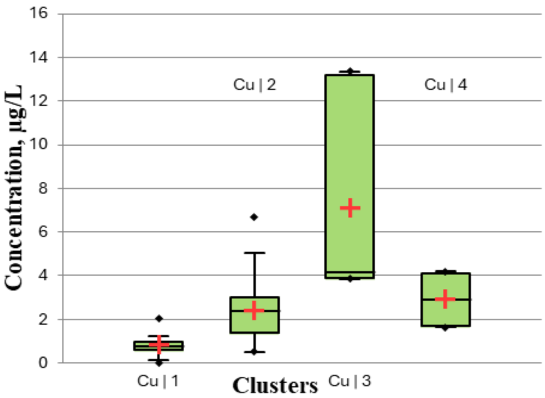
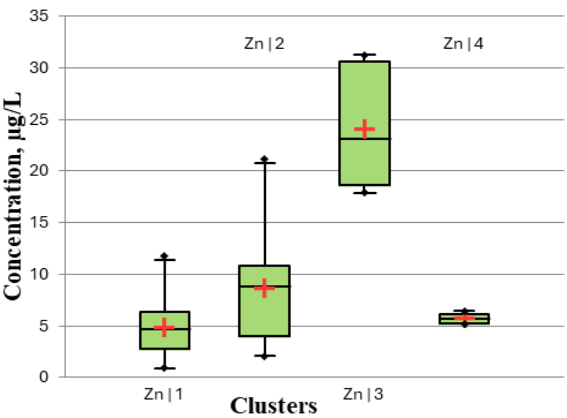
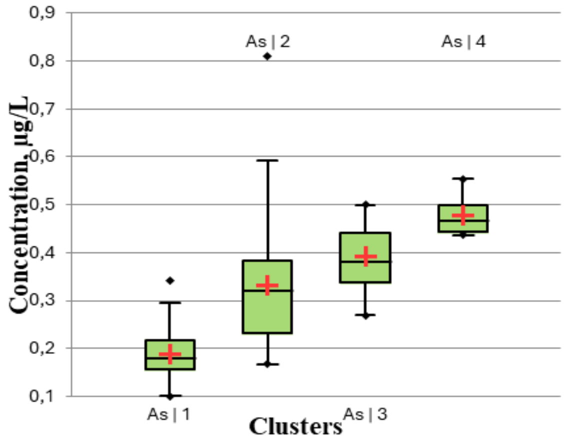


Figure 4
Zn concentration in each cluster



The results of As concentration analysis in clusters are represented in Figure 5. Cluster 1: As concentration is the lowest among all clusters, with values centred around 0.1 to 0.2 μg · L^{-1}. The range is minimal, indicating low variability and consistent environmental conditions with limited As pollution sources. This cluster may represent less industrialized or rural areas. Cluster 2: the highest As concentration is observed in this cluster, with values reaching up to 0.8 μg · L^{-1}. There is a wide range of As levels, with an outlier indicating potential localized pollution spikes. This cluster likely includes significant pollution sources, such as industrial activities or agricultural runoff, as several monitoring points in cluster 2 are located near agricultural areas (monitoring points located along Lithuanian highway). Cluster 3: moderate As concentrations are seen in this cluster, with values ranging between 0.2 and 0.6 μg · L^{-1}.

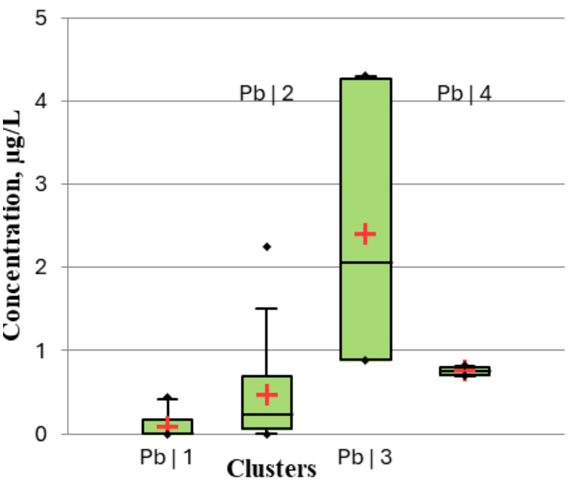
Figure 5
As concentration in each cluster



The wider interquartile range reflects variability in As levels, possibly due to mixed land-use or multiple pollution sources. The cluster indicates the presence of moderate human or industrial activity. Cluster 4: the As concentration in this cluster is the highest and relatively stable, ranging between 0.3 and 0.4 μg · L^{-1}. The narrower range suggests consistent pollution levels, likely from specific localized sources. This cluster reflects moderate human or industrial influence, less variable than Cluster 3.

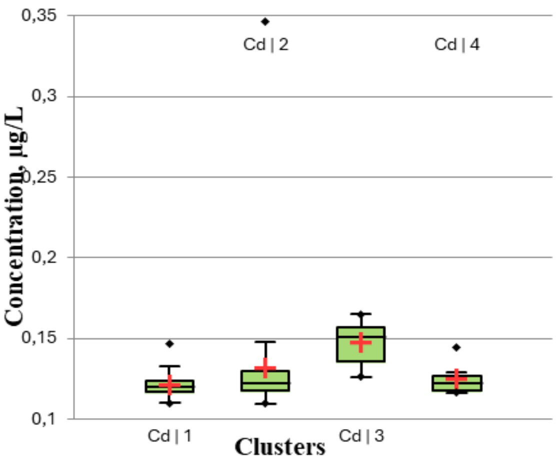
Pb concentration across clusters is illustrated in Figure 6. Cluster 1: minimal pollution. Pb levels are the lowest, around 0.5 μg · L^{-1}, with minimal variability. Likely represents rural or suburban areas with limited pollution sources.

Figure 6
Pb concentration in each cluster



Cluster 2: moderate pollution. Concentrations reach up to 1 μg · L^{-1} with some variability, suggesting mixed pollution sources like vehicle emissions or small-scale industry.
Cluster 3: high pollution. This cluster shows the highest Pb levels, nearly 4 μg · L^{-1}, with significant variability. Likely linked to heavy industry or traffic emissions, requiring focused mitigation. Cluster 4: low and stable levels. Concentrations are stable around 0.5 μg · L^{-1}, reflecting limited and consistent pollution sources, possibly from controlled environments.
Cd concentration analysis across clusters is represented in Figure 7. Cluster 1: minimal Cd pollution. Cd levels are low, around 0.1–0.15 μg · L^{-1} with minimal variability.

Figure 7
Cd concentration in each cluster



This suggests limited pollution sources, likely representing less industrialized or rural areas. Cluster 2: moderate Cd pollution. This cluster shows slightly higher Cd levels, with occasional outliers reaching up to 0.35 μg · L^{-1}. The variability indicates potential localized pollution sources, such as industrial runoff or emissions. Cluster 3: consistent but moderate levels. Cd levels are moderate, ranging from 0.1 to 0.2 μg · L^{-1}, with a tighter range compared to Cluster 2. The relatively consistent levels suggest stable but moderate pollution sources, likely from small-scale industry or urban activities. Cluster 4: stable and low levels. Cd concentrations are similar to Cluster 1, around 0.1 μg · L^{-1} with a few outliers. This reflects limited pollution, likely from controlled or natural sources.
The study of heavy metal concentrations in urban environments, particularly in Jelgava, reveals significant spatial variations that are closely linked to industrial activities and road traffic. The findings indicate that areas near industrial zones and major transportation routes exhibit elevated levels of metals such as Pb, Ni, and Cd, often exceeding regulatory limits. This observation is consistent with previous research that has established a strong correlation between proximity to industrial and high- traffic areas and increased pollution levels.
For instance, studies have shown that urban areas with high traffic density and industrial activities tend to have higher concentrations of heavy metals due to emissions from vehicles and industrial processes (Li et al., 2010; Saulnier et al., 2020; Liu et al., 2023).
A noteworthy aspect of this study is the innovative use of snow sampling as a proxy for assessing airborne pollution. Snow acts as a natural accumulator of airborne pollutants, enabling researchers to detect trace metal concentrations effectively in urban environments. This method is particularly advantageous in colder climates where snow cover is prevalent, allowing for a spatially comprehensive assessment of air pollution without the need for continuous air sampling. Previous studies have highlighted the effectiveness of snow sampling in capturing recent emissions, particularly during winter when heating activities and industrial processes are intensified (Berisha et al., 2016; Pilecka et al., 2018; Zhang, 2023). However, it is important to note that the method is limited by seasonal variability, and the timing of sample collection can significantly influence the results (Li et al., 2010; Zhang et al., 2015).
The variations in pollution levels across different clusters suggest that industrial emissions are a primary source of certain metals, particularly Ni and Cu, which are found at elevated levels near industrial facilities. Additionally, the high concentrations of Pb near major roads indicate that vehicular emissions continue to be a significant contributor to urban pollution, despite existing regulations aimed at reducing Pb emissions from transportation sources (Saeedi et al., 2012; Dong et al., 2017). This finding emphasizes the urgent need for targeted pollution control measures in industrial and high-traffic areas to mitigate health risks associated with long-term exposure to these toxic elements (Zhao et al., 2012; Zhong et al., 2015).
While the study provides valuable insights into the spatial distribution of heavy metal pollution in Jelgava, it also acknowledges several limitations that warrant further investigation. Expanding sampling efforts to include other seasons could help determine whether the observed contamination patterns are consistent year-round or specific to winter conditions. Additionally, incorporating other bioindication methods, such as moss or lichen sampling, could complement snow sampling by offering year-round pollution data and enhancing the understanding of trace metal deposition rates over extended periods (Zhao et al., 2012; Berisha et al., 2016).
This research highlights the importance of continuously monitoring air quality in urban centres, particularly those with significant industrial activity. By identifying pollution hotspots, the study offers a basis for informing targeted policy interventions, including the implementation of stricter emission

regulations for industrial sources and the expansion of air quality monitoring efforts in residential zones.
These findings also highlight the importance of integrating environmental considerations into urban planning to reduce human exposure to airborne pollutants, ultimately improving public health outcomes in industrialized cities (Guo et al., 2012; Abah et al., 2014; Kang et al., 2017).

Conclusions

1. The study successfully identified sampling and industrial locations and created corresponding maps. Cluster analysis was conducted, and areas with relatively low, medium, and high concentrations were identified.
2. The study successfully identified specific areas within Jelgava with elevated concentrations of heavy metals, particularly near industrial zones and major roadways. This confirms that industrial activities and vehicular emissions are primary sources of urban air pollution in the city, contributing significantly to Pb, Ni, and Cd levels above regulatory thresholds. Although the Latvian regulatory thresholds apply to annual average concentrations in ambient air and surface waters, these values provide a useful benchmark for evaluating the potential sources and risks of the heavy metals detected in snow samples.
3. Snow sampling proved to be an effective method for assessing airborne pollution, serving as a reliable proxy for detecting trace metals in urban environments. This approach provided comprehensive spatial data on pollution distribution and highlighted the potential of snow sampling as a cost-effective and practical method for air quality monitoring in colder climates.
4. The timing of sample collection, following the first snowfall, indicated that seasonal factors, especially heating during the winter, exacerbated air pollution. This finding underscores the importance of seasonal air quality management, particularly in winter, to address increased emissions from heating and industrial activities.
5. The elevated levels of heavy metals in urban areas near industrial facilities and high-traffic roads present potential health risks for residents, especially vulnerable populations such as children and the elderly. Long-term exposure to metals like Pb and Cd is associated with respiratory, neurological, and cardiovascular health issues, highlighting the need for targeted interventions to reduce human exposure in affected areas.
6. The study highlights the need for enhanced air quality monitoring and stricter regulatory measures to control industrial emissions in Jelgava. To build on these findings, future research should expand sampling efforts to include additional seasons and incorporate a variety of bioindication methods. In particular, collecting snow samples prior to firework events – such as during the second half of December before New Year's Eve – and at other key periods thorough the year would help assess whether elevated metal concentrations are confined to late winter or persistent year-round. Such comprehensive data collection would support a more detailed understanding of temporal pollution patterns and inform the development of more effective, targeted mitigation strategies.

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