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Evaluation of the Composition of Settleable Aerosols in the Urban Area of Espíndola Canton, Loja Province, Ecuador

Evaluación de la composición de aerosoles sedimentables en el área urbana del cantón Espíndola, provincia de Loja, Ecuador

David Emmanuel del Pozo, María de los Angeles Alvarez* and Bryan Gabriel Valle

Universidad Técnica Particular de Loja, Ecuador. [https://ror.org/04dvbth24]

*Corresponding author: mdalvarez8@utpl.edu.ec, mddel@utpl.edu.ec

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Abstract

The present study analyzes the composition and concentration of settleable particulate matter (SPM) in the urban area of the Espíndola canton. It is based on the limited information available regarding air quality in small rural communities, where vehicular emissions and material extraction represent sources of pollution. The objective is to determine the concentration and chemical composition of SPM, specifically the presence of heavy metals such as cadmium (Cd), chromium (Cr), lead (Pb), and copper (Cu), comparing the SPM concentration results with Ecuador's environmental regulation (Ministerial Agreement 097-A), which establishes a limit value of 1 mg/cm^2 over 30 days. The methodology involved systematic sampling over five months at five points within the urban area. Using gravimetric methods and chemical analyses, results were obtained based on SPM concentrations. Although levels were below the maximum permissible limit, the presence of heavy metals was identified in the SPM samples. The distribution of these metals showed a stronger correlation with monthly variations than with land use. It is concluded that, while SPM levels comply with environmental regulations, the presence of heavy metals cannot be ruled out. These findings highlight the importance of continuously monitoring air quality in rural regions such as Espíndola, where human activities, although limited, may contribute to atmospheric pollution and the dispersion of toxic elements.

Keywords: Settleable particulate matter, heavy metals, air pollution, gravimetric methods.

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Resumen

El presente trabajo analiza la composición y concentración del material particulado sedimentable (MPS) en el área urbana del cantón Espíndola, con base en la limitada información sobre la calidad del aire en pequeñas comunidades rurales donde las emisiones vehiculares y la extracción de materiales representan fuentes de contaminación. Se planteó como objetivo determinar la concentración y composición química del MPS, específicamente la presencia de metales pesados como el cadmio (Cd), cromo (Cr), plomo (Pb) y cobre (Cu), comparando los resultados de las concentraciones de MPS con la normativa ambiental del Ecuador (Acuerdo Ministerial 097-A), que establece un valor límite de 1 mg/cm^2 por 30 días. La metodología empleó un muestreo sistemático durante cinco meses en cinco puntos del área urbana; por medio de métodos gravimétricos y análisis químicos se obtuvieron los resultados con base en las concentraciones de MPS, los cuales, pese a encontrarse por debajo del límite máximo permisible, identificaron la presencia de metales pesados en las muestras. La distribución de estos metales mostró mayor correlación con las variaciones mensuales que con el uso del suelo. Se concluye que, si bien los niveles de MPS cumplen con la normativa ambiental, no se exime la presencia de metales pesados. Estos hallazgos resaltan la relevancia de monitorear continuamente la calidad del aire en regiones rurales como Espíndola, donde las actividades humanas, aunque limitadas, pueden contribuir a la contaminación atmosférica y a la dispersión de elementos tóxicos.

Palabras clave: Material particulado sedimentable, metales pesados, contaminación atmosférica, métodos gravimétricos.

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Orcid IDs:

David Emmanuel del Pozo Meza: https://orcid.org/0009-0008-9162-7410
María de los Angeles Alvarez Correa: https://orcid.org/0009-0008-5236-9498
Bryan Gabriel Valle Esparza: https://orcid.org/0009-0002-0689-7640

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1 Introduction

Air quality is a global issue that is not limited to a specific region, as air knows no geographical boundaries (Pérez Cárdenas, 2017). Air pollutants, such as settleable particulate matter (SPM), can be carried by the wind and affect less polluted areas, causing adverse effects on human health, ecosystems, and food security (OPS, 2018). SPM is defined, according to Annex 4 of Ministerial Agreement 097-A, as solid or liquid particles that, due to the force of gravity, settle on a horizontal surface, and whose size allows them to be collected in static devices over a specific period.

These particles are associated with various sources, both natural and anthropogenic. Among the former are pollen, spores, wildfires, and volcanic eruptions (Suárez and Vásquez, 2017). However, human activities, such as the combustion of fossil fuels, industrial activities, and vehicular transportation, generate the largest number of pollutants (Morocho, 2024).

Settleable particulate matter (SPM) is an important component of air pollution (P. Santillán et al., 2021). This includes particles with an aerodynamic diameter greater than 10 micrometers ($PM_{>10}$), which, due to their size, do not remain suspended in the air for long, quickly settling on the ground and other surfaces (Suárez and Vásquez, 2017). Its chemical composition includes both heavy metals (Cd, Cr, Pb, Cu, Mg, Zn, Al, Ni, Mn) and anions (chlorides, nitrates, and sulfates), which pose a significant risk to human health and the environment due to their toxicity and ability to accumulate in the food chain (Reyes et al., 2016; Mejía et al., 2018).

In Ecuador, air quality issues affect both large cities and rural areas with less industrial development (López et al., 2022). Cities such as Quito and Cuenca have stood out for their investment in resources dedicated to monitoring atmospheric pollutants, including settleable particulate matter, which has allowed for the identification of concentrations of up to $2.86\ \mathrm{mg/cm^2}$ over 30 days in the city of Quito, according to the 2013 environmental quality report (Municipio del Distrito Metropolitano de Quito, 2015). On the other hand, in the city of Cuenca, lower concentrations of settleable particulate matter have been recorded, ranging from 0.28 to $0.35\ \mathrm{mg/cm^2}$ over 30 days (EMOV EP, 2021), reflecting the presence of variable concentrations of SPM, even in areas with more intensive monitoring.

Some studies have shown that factors such as wind-blown resuspension of urban dust and vehicular traffic are significant sources of settleable particulate matter, especially in areas with poor road infrastructure or slow-moving traffic, which, in combination with seasonal factors, contribute significantly to the distribution and concentration of SPM and its components in the air (Valencia et al., 2019; Villacis, 2023). Despite this, studies on air pollution in small rural areas are limited or nonexistent, highlighting the importance of research evaluating the composition and effects of settleable particles in these locations (Solórzano, 2023).

The Espíndola canton, in the province of Loja, presents a unique context as it is a border area with constant heavy transport traffic, compounded by the presence of extractive activities that could contribute to the emission of air pollutants affecting the health of the 1388 inhabitants residing in its urban area (INEC, 2001). For this reason, the main objective of this study is to evaluate the composition of settleable aerosols in the urban area of the Espíndola canton, with an emphasis on identifying the concentration of settleable particulate matter and assessing the presence of heavy metals in its composition.

2 Materials and Methods

2.1 Study Area

The study was conducted in the urban area of the Espíndola canton, in the Amaluza parish, where five representative areas were selected using stratified random sampling.

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Table 1. Distribution of sampling areas

Sector	Point	Land Use	Description
Center	1	CM	Urban center with heavy vehicle traffic.
Terminal	2	EQ2	Characterized by a continuous flow of vehicles.
River	3	IND	Presence of auto repair shops, spas, and nearby aggregate mining.
Dolorosa	4	R1	Close to unpaved roads.
School	5	EQ1	High traffic volume associated with school hours.

Sampling points and distribution based on land use. Commercial (CM), Social Services Facilities (EQ1), Public Services Facilities (EQ2), Industrial (IND), Residential (R1).

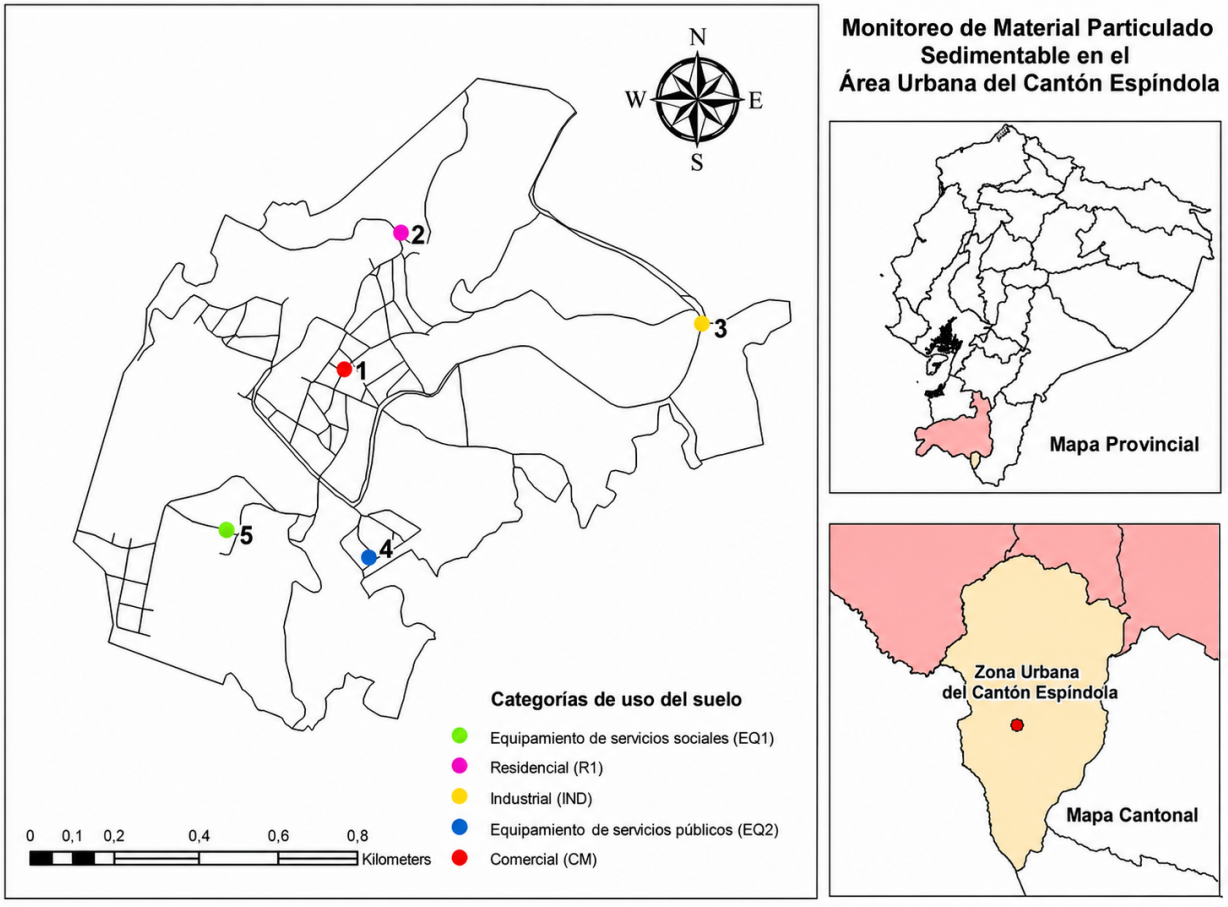


Figure 1. Map showing the location of sampling areas.

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2.2 Meteorological information for the Espíndola canton

To complement the SPM sampling, available information on the prevailing meteorological conditions in the Espíndola canton during the sampling period was compiled. According to historical data from the National Institute of Meteorology and Hydrology (Instituto Nacional de Meteorología e Hidrología (INAMHI), 2024) and the Decentralized Autonomous Municipal Government of Espíndola (Gobierno Autónomo Descentralizado (GAD) Municipal de Espíndola, 2015), during this period (March–July), there is a marked transition between the rainy and dry seasons in the region. Therefore, variables such as precipitation, wind speed, and wind direction were collected and considered in the analysis of results, with the aim of relating them to the dynamics of settleable particulate matter.

2.3 Design and installation of samplers

The settleable particulate matter (SPM) collectors were designed in accordance with Method 502 of the *Methods of Air Sampling and Analysis* (Intersociety Committee, 1988) and in compliance with Ministerial Agreement 097-A. They are made of 15.24 cm diameter PVC pipe and a funnel of the same size, connected to a one-gallon plastic container. The top features an electro-welded mesh that filters out coarse contaminants, ensuring representative samples. The collectors were installed more than 2.5 meters above ground level.



Figure 2. Settleable Particulate Matter Collector.

2.4 Sample Collection

The sampling period lasted five consecutive months, covering two seasonal periods between March and July 2024. Samples were collected every 30 days in accordance with the guidelines established in Annex 4 of Ministerial Agreement 097-A. Once this period had elapsed, the samples were removed, after first washing them with distilled water to dislodge the particles adhering to both the walls of the collector tube and the funnel, directing them into the collection container. Finally, a new container was installed for collecting the following month's sample.

The samples taken to the laboratory were separated into soluble and insoluble fractions using the gravimetric method.

2.5 Gravimetric Analysis

To quantify settleable particulate matter (SPM), 47 mm quartz filters and porcelain capsules were used, dried at 105 °C in an oven to be weighed before and after filtration. The vacuum filtration equipment allowed for the efficient retention of particles on the filters. The SPM concentration was calculated in $\mathrm{mg/cm^2}$ over 30 days, using the difference in weight between the filters and capsules before and after the process, by applying the following formulas in Microsoft Excel:

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The settling rate of insoluble particles was determined using the equation (1):

$$Cf = \frac{Pf - Pi}{AT} \quad (1)$$

Where: Cf is the concentration of insoluble particles; Pi is the initial weight of the filter before filtration; Pf is the final weight of the filter after filtration; A represents the cross-sectional area of the particle precipitation vessel, expressed in m^2; and T is the duration of the monitoring period (30 days).

The equation was used to calculate the settling rates of soluble particles (2):

$$Cs = \frac{(Mfs - Mis)}{AT}\frac{V1}{V2} \quad (2)$$

Where: Cs is the concentration of soluble particles; Mis is the initial weight of the capsule before filtration; Mfs is the final weight of the capsule after filtration; A is the cross-sectional area of the particle precipitation vessel in m^2; T denotes the duration of the monitoring period (30 days); $V1$ corresponds to the volume of all the filtered liquid expressed in litres; and $V2$ is equivalent to the volume of all the extracted liquid converted to litres.

Finally, the total particle fallout rate was calculated using the equation (3):

$$Ct = Cu + Cs \quad (3)$$

Where: Ct represents the total particle deposition rate expressed in g/m^2 per month; Cu is the deposition rate of insoluble particles in g/m^2 per month; and Cs is the deposition rate of soluble particles, also expressed in g/m^2 per month.

2.6 Comparison with established limits for SPM

To determine whether particulate matter concentrations exceed the recommended limits, the values stipulated in Annex 4 of Ministerial Agreement 097-A were used as a reference, as detailed in Table 2.

Table 2. Maximum permissible limit for SPM

Ecuadorian Environmental Legislation TULSMA AM - 097 Annex 4
1 mg/cm^2 for 30 days

The reference value corresponds to a concentration accumulated over 30 days.

2.7 Acid digestion and metal analysis

To assess heavy metals in settleable particulate matter (SPM), microwave-assisted acid digestion was performed. The samples were incinerated at 500 °C for three hours to remove organic matter, then treated with 9 ml of nitric acid (HNO3) and 3 ml of hydrofluoric acid (HF). The mixture was digested in a microwave following US EPA Method 3052, cooled, filtered, and diluted to 25 ml with distilled water.

Heavy metal concentrations were determined by atomic absorption spectroscopy (AA), using certified standards to ensure the accuracy of the analysis. Four metals were selected: copper (Cu), lead (Pb), cadmium (Cd), and chromium (Cr), due to their high toxicity and common presence in anthropogenic sources associated with transportation and extractive activities (Morales Tates et al., 2024; Dall'Osto et al., 2014). Furthermore, this selection was based on the availability of supplies and reagents and on the main objective of the study, which aimed to identify the presence or absence of heavy metals in settleable particulate matter.

3 Results and Discussion

The climatic conditions recorded in the Espíndola Canton are described in Table 3. During the five months of monitoring, the canton underwent a seasonal transition characteristic of Ecuador's southern Andean region, shifting from a rainy season to a dry season, as reflected in the decrease in precipitation and the increase in wind speed beginning in May.

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Table 3. Climatic conditions in the Espíndola Canton

Month	Average Precipitation (mm)	Average Wind Speed (km/h)	Predominant Direction
March	160–200	8–12	East — Northeast
April	130–170	9–14	East — Northeast
May	60–90	11–16	East — Northeast
June	25–45	14–20	East — Northeast
July	10–25	15–22	East — Northeast

Precipitation intervals, wind speed and prevailing wind direction.

Table 4. Chemical characterization of SPM

Land Use	Point	Month	SPM (mg/cm^2 × 30 days)	Cd (μg/L)	Cu (μg/L)	Pb (μg/L)	Cr (μg/L)
CM	1	March	0.17	51.4	262.3	696.5	5.7
EQ1	2		0.22	217.4	282.1	1 042.2	21
IND	3		0.43	49.3	310.7	919.9	100.5
R1	4		0.28	41.2	234.1	872	7
EQ2	5		0.3	28.3	150.4	563.5	0
EQ1	2	April	0.39	31.4	157.2	662.5	69
IND	3		0.42	28.8	180.1	777.2	0
R1	4		0.22	25.1	131.8	580	0
EQ2	5		0.28	684	176.3	910.2	95.1
CM	1	May	0.3	46.3	320	908.7	8.3
EQ1	2		0.31	67.1	277.6	837.6	89
IND	3		0.35	81.7	257.6	836.3	87.1
R1	4		0.27	108	213.7	758.3	72.5
EQ2	5		0.38	130.9	353.6	1 235.2	163.1
CM	1	June	0.25	38	242.6	769.9	0
EQ1	2		0.27	39.2	192.9	771.3	76.9
IND	3		0.51	43.8	350.3	910.5	95.5
R1	4		0.33	41.3	365.1	1 075.2	38
EQ2	5		0.25	19	130.5	538.6	0.3
CM	1	July	0.21	20.1	116	538.5	0
EQ1	2		0.3	17.7	112.8	536.8	0
IND	3		0.33	9.2	111.8	537.3	0
R1	4		0.27	19	216.6	703	68
EQ2	5		0.23	19.3	109.6	509.8	29

SPM is expressed in mg/cm^2 over 30 days, and Cd, Cu, Pb and Cr in μg/L. No SPM concentrations exceeding the regulatory limit of 1 mg/cm^2 over 30 days were recorded.

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The concentrations of settleable particulate matter (SPM) and heavy metals (Cd, Cu, Pb, Cr) obtained during five months of continuous monitoring across different land uses are presented in Table 4. Although SPM concentrations remained within the maximum permissible limits set by Ecuadorian environmental regulations, the analysis revealed the presence of heavy metals, with lead being the most abundant element. Although Ecuador phased out lead in gasoline in 1998 (Ministerio de Energía y Minas, 1998), its effects persist due to the historical accumulation of this metal in soils and sediments, which can be released back into the environment (Tong et al., 2016). In Latin America, the combination of agricultural sources, residues from leaded fuels, and deteriorated construction materials generates complex atmospheric profiles (Bergametti et al., 2020; Iglesias et al., 2012). This presence of heavy metals is consistent with reports in the literature, where they are associated with industrial processes, vehicle wear, and abrasion of their metal components (Huang et al., 2022).

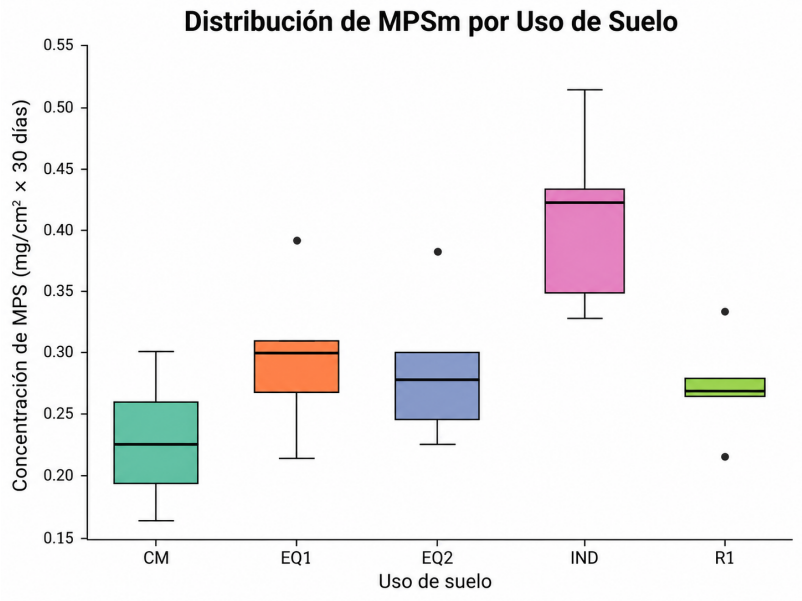


Figure 3. Box plot showing concentrations of settleable particulate matter by land use.

Figure 3 shows the concentrations of settleable particulate matter (SPM) at each sampling point, highlighting sampling point number 3 (IND), located in an industrial area, as the one with the highest concentrations, with an average of $0.41\ \mathrm{mg/cm^2}$ over 30 days and a maximum peak of $0.51\ \mathrm{mg/cm^2}$ over 30 days. These values could suggest the combined influence of stationary and mobile sources in the industrial zone, such as aggregate extraction and heavy vehicle traffic, factors that contribute to the release and dispersion of particles in the area (Alloway, 2013; Muñoz P. et al., 2021). Similarly, in industrial areas, other sources may be involved, such as auto repair shops and local aggregate processing activities, which, although not always formally registered, can emit particles enriched with metals such as Cu and Cr. These sectors, by generating resuspended dust and wear on metallic materials, represent a significant source of atmospheric pollutants in unregulated urban and industrial environments (Huang et al., 2022; BaLich et al., 2024). On the other hand, point 1 (CM), associated with commercial land use, had the lowest concentrations, with an average of $0.23\ \mathrm{mg/cm^2}$ over 30 days.

Figure 4 shows the SPM concentrations over the five-month monitoring period, revealing relative stability in the monthly averages, which range from 0.27 to $0.33\ \mathrm{mg/cm^2}$ over 30 days. Although this period experimented a climatic transition marked by a gradual decrease in rainfall and an increase in wind speed from May onward (Table 3), no signifi-

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cant differences were observed in average SPM concentrations between months, indicating that meteorological conditions alone do not fully explain the variability of settleable particulate matter. The decrease in precipitation could reduce the atmospheric washing of particles, while the increase in wind speed favors the resuspension of previously deposited particles, facilitating particle transport—an effect that can be amplified on unpaved surfaces, dry agricultural areas, and industrial areas with low vegetation cover (Zhao et al., 2018).

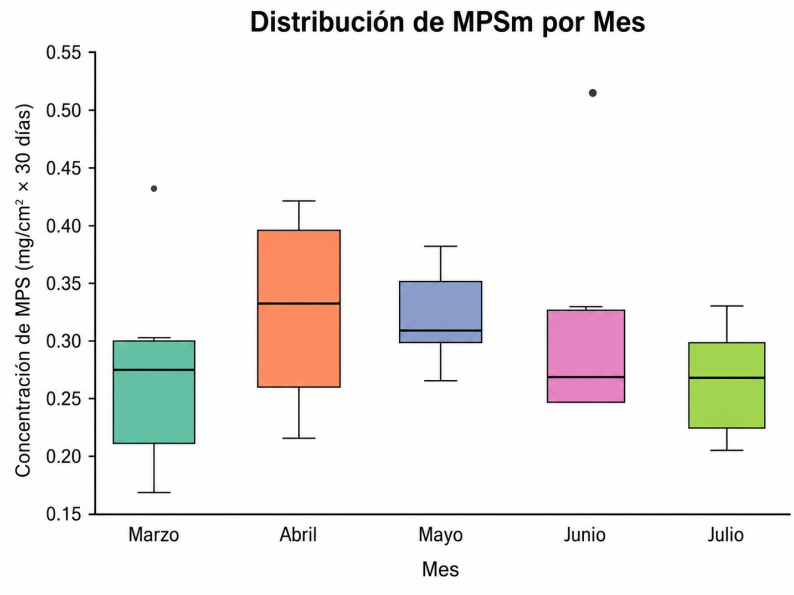


Figure 4. Box plot showing concentrations of settleable particulate matter by month.

Furthermore, when analyzing the dispersion of the data, it can be observed that concentration ranges tend to be narrower in the driest months, which could be due to factors such as land use type, traffic intensity, and local activities that exert a greater influence on SPM concentrations. This can be observed during the month of June, when the highest concentration of the study ($0.51\,\mathrm{mg/cm^2}$ over 30 days) was recorded in the industrial use zone (IND).

Figure 5 shows the results of the nonparametric Kruskal-Wallis test, revealing significant differences in SPM concentrations according to land use ($p = 0.020$), suggesting that levels of settleable particulate matter vary depending on the activities and environmental characteristics specific to each zone.

Similarly, the Kruskal-Wallis test applied to monthly concentrations (Figure 6) shows statistically significant differences for Cd, Cu, and Pb ($p = 0.006$, 0.015 and 0.038, respectively). These monthly fluctuations could be attributed to factors such as the topography of Espíndola and atmospheric transport dynamics, which could facilitate the transport of pollutants from other areas depending on weather conditions, as well as the seasonality of agricultural activities.

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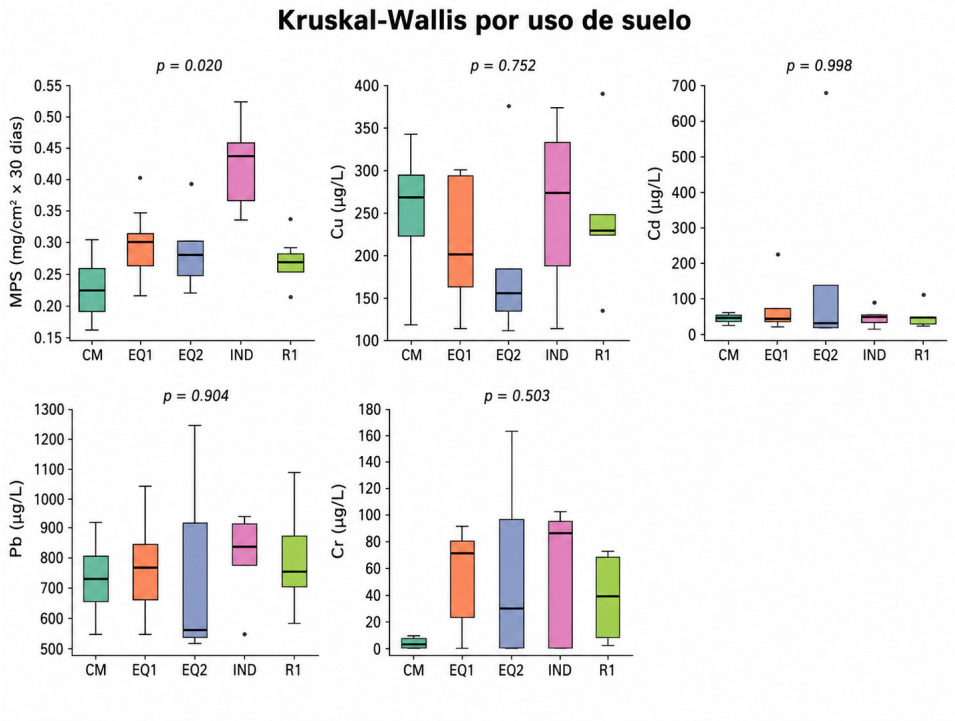


Figure 5. Kruskal-Wallis test for differences in means between SPM and metal concentrations by land use.

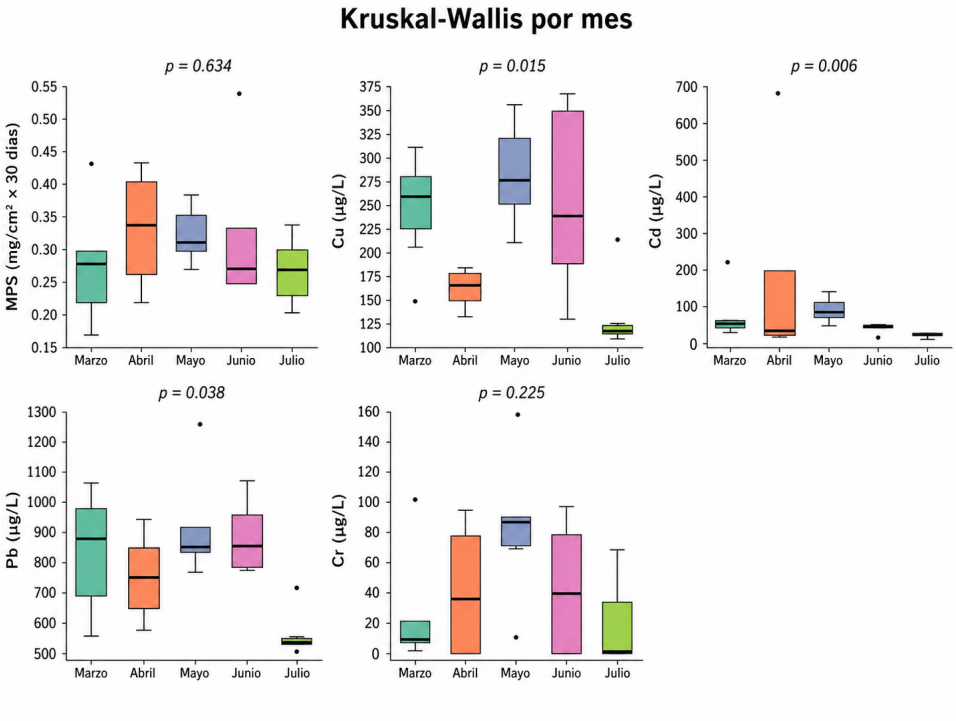


Figure 6. Kruskal-Wallis test for differences in means between monthly SPM concentrations.

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Spearman's correlation analysis, the results of which are summarized in Figure 7, revealed a significant positive correlation between Pb and SPM ($r = 0.421$, $p = 0.040$), as well as between Cr and SPM ($r = 0.435$, $p = 0.033$), suggesting that these metals tend to accumulate or be transported together with settleable particulate matter, possibly due to their affinity for solid particles present in the air and soil (Guo et al., 2021; Zhao et al., 2018). In addition, significant correlations were observed between the metals Cd, Cu, Pb, and Cr, with a particularly strong relationship between Pb and Cu ($r = 0.893$, $p = 0.000$), pointing to the possibility of a geochemical interaction or a common emission source caused by vehicular traffic, tire abrasion, brakes, and fuels, as well as resuspended dust in unpaved urban areas (BaLich et al., 2024; Cesari et al., 2012; Huang et al., 2022).

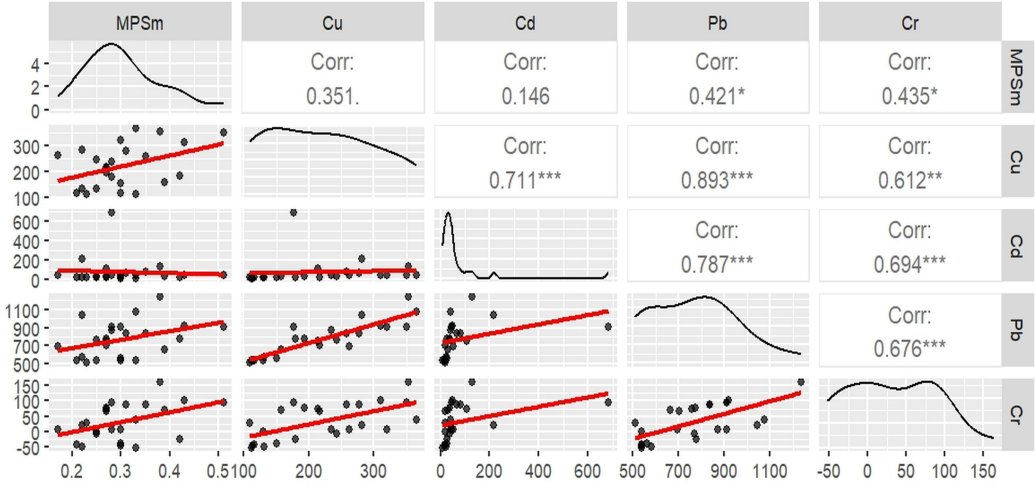


Figure 7. Spearman's correlation matrix between settleable particulate matter and the metals analysed.

These correlations among metals could be influenced by agro-environmental conditions and soil management in Espíndola. Specifically, the application of phosphate fertilizers and pesticides on crops such as coffee and sugarcane—common practices in the region—could explain the presence of Cd, as noted by Alloway (2013), who identifies these agricultural inputs as a significant source of this metal in the soil. Additionally, the persistence of Pb and Cu in organic and mineral particles, as has been documented in areas impacted by agricultural activities (Zhang et al., 2020; Wang et al., 2022), could contribute to the strong correlation observed between these two metals.

The observed correlation between heavy metals such as cadmium (Cd), chromium (Cr), lead (Pb), and copper (Cu) in settleable particulate matter is more influenced by monthly factors than by land use in the studied area. These metals can adhere to solid particles present in the air and soil, such as minerals (silicates and iron oxides) and organic matter, which act as vectors for their transport and accumulation in different areas (Saeedi et al., 2015). This behavior is due to the interaction of the metals with the surfaces of these particles, where they become trapped and protected from leaching processes, especially under windy conditions or mechanical disturbances caused by human activities (Guo et al., 2021; Zhao et al., 2018).

Pb and Cu tend to accumulate in areas impacted by agricultural activities, as their persistence in organic and mineral particles facilitates their accumulation in soils and sediments (Valdivieso et al., 2024). These associations are closely linked to the use of fertilizers and pesticides containing metal compounds, which intensify their presence in the environment (Villacis, 2023). In contrast, the mobility of metals such as Cr and Cd is higher in acidic environments, which is common in agricultural soils disturbed using fertilizers, pesticides, and tillage activities. According to Abad (2014), these compounds, when solubilized, can adhere to fi-

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ne particles and facilitate their airborne transport, especially under dry and windy conditions. This can be observed particularly during dry seasons, when reduced soil moisture and increased wind activity favor the dispersion of contaminated particles (Zhang et al., 2020; Wang et al., 2022).

This correlation pattern reflects the intrinsic properties of metals, such as their affinity for mineral and organic particles, as well as the possible influence of the specific climatic conditions of the study area (Zegarra et al., 2020). Seasonal variations, especially during dry periods, could intensify the mobility of metal-laden particles (Lara, 2022). Wind action during these seasons promotes the resuspension and transport of settleable particulate matter over long distances, redistributing metals in the environment (G. Santillán et al., 2025). This highlights how potential local climatic dynamics may contribute to the dispersion and accumulation of Cd, Cr, Pb, and Cu, resulting in concentration patterns marked by monthly variations (Wang et al., 2022; Zhang et al., 2020).

4 Conclusions

Specific increases were detected during certain periods, associated with possible local and seasonal factors. Furthermore, chemical characterization revealed the presence of heavy metals such as Cd, Cr, Pb, and Cu in the samples, even in areas with low total SPM concentrations. These findings highlight that, although SPM complies with established standards, its chemical composition may pose risks to the environment and human health.

Statistical correlations suggest that factors such as wind intensity, terrain topography, proximity to specific emission sources, and the mobilization of particles by human activities play a crucial role in the dispersion and accumulation of these elements. It was observed that local climatic dynamics, such as dry periods and particle resuspension, increase the presence of metals in the air.

Overall, the results indicate that the dynamics of settleable particulate matter in Espíndola are primarily determined by specific local conditions and the nature of emission sources, while climatic influence, although present, does not appear to be the predominant factor in the variability of SPM concentrations; however, an influence of climatic variation on metals (Cd, Pb, Cu) was found over the course of the months.

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Declaration on the use of artificial intelligence

The authors DECLARE that, during the preparation of the article entitled "Evaluation of the Composition of Settleable Aerosols in the Urban Area of Espíndola Canton, Loja Province, Ecuador", generative artificial intelligence tools were used exclusively to assist with the translation and improvement of the wording of specific sections of the manuscript. These tools were not used for data analysis, interpretation, the generation of results, the drawing of conclusions, or to replace the authors' academic and scientific judgement.

The authors assume full responsibility for the content, originality, integrity, and final version of the article.

Author's contributions

M.A.A.C.: Conceptualisation, data analysis, sampling. **B.G.V.E.:** Statistics, sampling. **D.E.P.M.:** Experimental design, data analysis.

References

Abad, M. (2014). *Fitotoxicidad del material particulado sedimentable (MPS) generado en la zona urbana del cantón Cuenca.* Online: https://short-url.cc/1yHlV (Disponible en línea)

Alloway, B. J. (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability*. Springer. Online: https://short-url.cc/1taxP

©2026, Universidad Politécnica Salesiana, Ecuador.

BaLich, P., Anh Duc, T., Huy Thong, V., and Van Linh, N. (2024). Geochemical speciation, pollution assessment, and source identification of heavy metals in sediment cores of the Cau River basin, Hai Duong province, Vietnam. *RSC Sustainability*. Online: https://short-url.cc/1taxY

Bergametti, G., Formenti, P., Desboeufs, K., and Triquet, S. (2020). Trace elements in atmospheric aerosols: Sources and implications. *Elements*, 339–344.

Cesari, D., Contini, D., Genga, A., Siciliano, M., Elefante, C., Baglivi, F., and Daniele, L. (2012). Analysis of raw soils and their re-suspended PM10 fractions: Characterisation of source profiles and enrichment factors. *Applied Geochemistry*, *27*(6), 1238–1246. Online: https://doi.org/10.1016/j.apgeochem.2012.01.006

Dall'Osto, M., Beddows, D. C. S., Gietl, J. K., Olatunbosun, O. A., Yang, X., and Harrison, R. M. (2014). Characteristics of tyre dust in polluted air: Studies by single particle mass spectrometry (ATOFMS). *Atmospheric Environment*, *94*, 224–230. Online: https://doi.org/10.1016/j.atmosenv.2014.05.033

EMOV EP. (2021). *Informe de calidad del aire Cuenca 2020-2021* (Inf. Téc.). Cuenca, Ecuador: Empresa Pública de Movilidad, Tránsito y Transporte de Cuenca. Online: https://short-url.cc/1yHmj

Gobierno Autónomo Descentralizado (GAD) Municipal de Espíndola. (2015). *Plan de Desarrollo y Ordenamiento Territorial de Espíndola 2014-2019* (Inf. Téc.). Espíndola, Loja, Ecuador: GAD Municipal de Espíndola. Online: https://short-url.cc/1yHmn

Guo, J., Li, X., Wang, Y., and Zhao, L. (2021). Adsorption of heavy metals onto soil minerals: A review of recent advances. *Journal of Hazardous Materials*.

Huang, L., Zhang, X., Meng, Y., Yu, Y., and Qi, M. (2022). Sources and formation mechanisms of heavy metals in road dust: A review. *Environmental Pollution*, *303*.

Iglesias, V., Carreras, H., Pongrac, C., Alvarez, L., and Mateos, A. (2012). Atmospheric lead deposition in the Argentine Pampas: Historical trends from c. 1995–2006 in a fast-developing agricultural region. *Environmental Pollution*, 140–147.

INEC. (2001). *Instituto Nacional de Estadística y Censos.* Online: https://goo.gl/iczP53

Instituto Nacional de Meteorología e Hidrología (INAMHI). (2024). *Datos históricos meteorológicos.* Quito, Ecuador. Online: https://geoservicios.inamhi.gob.ec/#/

Intersociety Committee. (1988). *Methods of air sampling and analysis*. Lewis Publishers. Online: https://short-url.cc/1yHmu

Lara, R. (2022). *Material particulado en suspensión y depósitos en la zona oeste de la aglomeración de Gijón* (Tesis Doctoral, Universidad de Oviedo). Online: https://short-url.cc/1yHmz

López, J., Correa, J., Cano, Y., and Bermúdez, J. (2022). Evaluación de los gases de combustión y material particulado en el aire de parqueaderos del distrito metropolitano de Quito, Ecuador. *Revista Científica ECOCIENCIA*, *19*.

Mejía, D., Zegarra, R., Astudillo, A., and Moscoso, D. (2018). Análisis de partículas sedimentables y niveles de presión sonora en el área urbana y periférica de Cuenca. *Revista de la Facultad de Ciencias Químicas*, *19*.

Ministerio de Energía y Minas. (1998). *Acuerdo Ministerial No. 112: Autorización para la producción y comercialización a nivel nacional de gasolinas extra y súper sin plomo.* Registro Oficial No. 308 del 30 de abril de 1998. Quito, Ecuador.

Morales Tates, J., Morocho, L., Garzón, L., and Cepeda, M. (2024). Evaluación de la concentración de material particulado sedimentable en Fertisa Sur de Guayaquil. *Polo del Conocimiento*, *9*(3), 9–24. Online: https://doi.org/10.23887/pc.v9i3.6697

Morocho, D. (2024). Fuentes de contaminación atmosférica en zonas rurales. *Ciencia y Desarrollo Ambiental*, 27–39.

Municipio del Distrito Metropolitano de Quito. (2015). *Informe de calidad del aire Quito* (Inf. Téc.). Quito, Ecuador: Dirección Metropolitana de Ambiente. Online: https://short-url.cc/1yHmE

Muñoz P., S., Salcedo R., J., and Sotomayor M., A. (2021). *Contaminación ambiental producida por el tránsito vehicular y sus efectos en la salud humana: revisión de literatura.* Online: https://goo.gl/abcd12

©2026, Universidad Politécnica Salesiana, Ecuador.

OPS. (2018). *Organización Panamericana de la Salud.* Online: https://short-url.cc/1yHmH

Pérez Cárdenas, A. (2017). Contaminación atmosférica: Una amenaza global. *Revista Internacional de Ciencias Ambientales*, 25–38.

Reyes, P., Morales, H., and Gómez, F. (2016). Impacto de los metales pesados en el ambiente y la salud humana. *Ciencia y Salud Ambiental*, 18–34.

Saeedi, M., Daneshvar, S., and Karbassi, A. (2015). Role of riverine sediment and particulate matter in adsorption of heavy metals. *International Journal of Environmental Science & Technology*. Online: https://www.bioline.org.br/pdf?st04017

Santillán, G., Rodríguez, M., Orozco, J., Paredes, M., Maldonado, C., and Rivadeneira, J. (2025). Determinación de la concentración de material particulado sedimentable en el barrio Juan Montalvo en el Cantón Riobamba. *TESLA Revista Científica*, *18*.

Santillán, P., Rodríguez, M., Orozco, J., Ríos, I., and Bayas, K. (2021). Evaluación de la concentración y distribución espacial de material particulado en los campus de la UNACH - Riobamba. *Scielo*. Online: https://short-url.cc/1yHmL (1 de diciembre)

Solórzano, P. (2023). *Monitoreo de material particulado sedimentable en la parroquia Coronel Marcelino Maridueña, provincia del Guayas durante el período 2023.* Online: https://short-url.cc/1yHmR

Suárez, L., and Vásquez, M. (2017). Composición y riesgos del material particulado. *Journal of Environmental Studies*, *10*(2), 56–67.

Tong, Y., Liu, X., and Zhang, Z. (2016). Status and phases of lead in typical garden soils from Beijing urban area. *Environmental Science and Pollution Research*.

Valdivieso, J., Coral, K., and Esteban, J. (2024). Determinación de la concentración de metales pesados mediante la caracterización de material particulado sedimentable en la reserva biológica Limoncocha, Ecuador. *Atena Editora*. Online: https://short-url.cc/1tayK (1 de abril)

Valencia, P., Sánchez, F., Tigua, M., and Mena, S. (2019). Cálculo referencial de material particulado en el aire como factor de contaminación en Pujilí. *Revista Científica Cienciamerica*, *8*(2), 15–24.

Villacis, O. (2023). *Plomo en material particulado sedimentable aledañas en terminales de transporte masivo, Guayaquil-Ecuador.* Online: https://short-url.cc/1tayN (Agosto)

Wang, F., Qiao, H., and Zhao, J. (2022). The influence of climatic variability on the resuspension and transport of sediment-bound heavy metals. *Environmental Research*.

Zegarra, R., Andrade, S., Parra, M., Mejía, D., and Rodas, C. (2020). Análisis espacial de PM10 en el aire y su composición de metales con relación a factores ambientales alrededor de centros de educación preescolar en Cuenca. *Maskana*. Online: https://short-url.cc/1yHn4 (29 de abril)

Zhang, Z., Chen, Y., and Xiao, H. (2020). High-efficiency solar evaporator prepared by one-step carbon nanotubes loading on cotton fabric toward water purification. *Science of the Total Environment*. Online: https://short-url.cc/1yHn9

Zhao, Y., Shao, M., and Zhang, Z. (2018). Heavy metals in agricultural soils from a typical mining region in China: Spatial distribution, risk assessment, and sources. *Ecotoxicology and Environmental Safety*.

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