Heavy metal content estimation in the Mexico City Street dust: an inter-method comparison and Pb levels assessment during the last decade

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Abstract

Elemental concentrations measured in 482 street dust samples from different urban and conurbated areas of Mexico City obtained using a portable energy-dispersive X-ray fluorescence spectrometer are reported. The data quality of eight different elements commonly used in pollution studies is evaluated, calculating the data precision and accuracy obtained with this handheld equipment. Precision for the various elements analyzed ranges between 1.2 and 15.9%, which can be considered as adequately precise for portable equipment. In the case of the accuracy, a maximum under-/overestimation of less than 20% was achieved. Pb and Zn correlation factors were 0.725 and 0.923, respectively. Similar mean Pb concentration values to those reported by ICP-OES were obtained. An average value of ~ 100 mg/kg for Pb concentration was estimated, which is significantly lower than the utmost permissible levels for residential/commercial usage. On the contrary, contamination factors calculated to identify the metal accumulation against those of the background values point from considerable to high contamination for 62 and 30% of the street dust samples analyzed, respectively. A comparison of the results recorded in Mexico City 10 years ago against those obtained suggests that no significant reduction in Pb concentration has occurred during this period despite the measures implemented to stop using leaded gasoline for three decades. Finally, the sample's low-amount requirements, simple nondestructive preparation procedure, and rapid elemental concentration determinations make portable XRF a promising geochemical determination technique for the fast and economic evaluation of contamination by heavy metals in large cities.

Keywords Street dust · Heavy metal content · Contamination factor · Portable ED-XRF spectrometry

1 Introduction

The year 1987 is likely remembered by many of Mexico City's inhabitants as the day when its streets were covered with thousands of bird's corpses. As a result of some investigations, remains of heavy metals (HM) and gases

were reported in the bird's body; lead, cadmium, radon, and asbestos were found in their bronchi [1]. Thirty-two years later, Mexico City dawned with the first environmental contingency of 2019 as the result of the burning of pyrotechnics and bonfires during the New Year's celebration. During the second half of May 2019, the inhabitants

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of Mexico City and the State of Mexico lived with low air quality for four days due to high temperatures, fires, and low-speed winds, according to authorities [2].

Air quality is measured by the *Environmental Commission of the Megalopolis* (CAME) through the 55 stations that make up the monitoring system in the Megalopolis (constituted by six entities: Mexico City, Estado de México, Hidalgo, Morelos, Puebla, and Tlaxcala), which measures every hour the scale of pollutants in the air, allowing them to identify whether it is optimal or poses a health risk. Besides managing the environmental policies, CAME is responsible for triggering the environmental contingency phases when the Metropolitan Zone of the Valley of Mexico (MZVM) records low air quality. Due to this continuous monitoring, five environmental contingencies were reported in 2019 in the MZVM.

Besides air pollution, water pollution and soil pollution have been widely studied, and there are environmental standards for their regulation [3]. On the contrary, dust pollution studies are scarce and there are no official rules which regulate the presence of dust in the environment [4]. Although dust comes from both natural and anthropic sources, street dust (SD) is mainly composed of particles derived from anthropic processes [5].

SD consists of a heterogeneous assortment of materials; some originated from natural processes (weathering of rocks, resuspension of soil particles by wind action, volcanic ash, pollen, other plant fragments, etc.). Anthropogenic activities (industry, vehicular traffic that produces particulate matter due to roads, brakes and tires wear, and exhaust emissions; construction and its associated materials; agricultural burning; mining; etc.) also originate SD, which is later released to the environment [6, 7].

As stated by Bautista et al. [8], fine particles of anthropic origin, particulate matter 10 μm in diameter or less (the so-called PM_{10} particles), are hosted by the SD, which contain magnetic minerals and traces of heavy metals (Cr, Cu, Pb, Zn, etc.). Due to their particular size and shape, PM_{10} particles can be inhaled by humans, which is why SD is considered as a significant source of breathable air pollution [9].

Nowadays, Mexico City has 23 and a half million inhabitants, there are 40,000 small- and medium-sized industries of various types, and 9.5 million motor vehicles circulate [10]. Because of these facts, together with the geological and geographic characteristics, relief, drainage, and wind direction, Delgado-Carranza et al. [4] considered that almost all of Mexico City is likely contaminated by heavy metals contained in the SD.

Different conventional techniques have been used to estimate the SD chemical composition (e.g., atomic absorption spectrometry (AAS), inductively coupled plasma mass spectrometry (ICP-MS), scanning electron microscopy (SEM-EDS), and X-ray fluorescence (XRF)

spectrometry). Recently, portable XRF spectrometers (ED-XRF) are preferred over conventional bench XRF spectrometers (WD-XRF) because of their versatility, speediness, reduced amounts of sample required, and, above all, their direct infield measurement and nondestructive sample preparation capability [11–14].

The purpose of this study is to evaluate, on the one hand, the data quality of eight different elements (V, Cr, Mn, Fe, Ni, Cu, Zn, and Pb) commonly used in pollution investigation. This first goal is accomplished by calculating the data precision and accuracy obtained from analyzing the geological reference material IGLs-1 (a lateritic soil) using a portable ED-XRF (Genius 7000XRF spectrometer). On the other hand, the results of 482 SD samples from different urban and conurbated areas of Mexico City (obtained with the same portable instrument) are compared against those obtained by conventional inductively coupled plasma optical emission spectrometry (ICP-OES), gathered and reported by Aguilera et al. [15]. Also, the comparison between current pollution Pb levels and those from the last decade in Mexico City suggests that no significant reduction in Pb concentration has taken place during ten years despite three decades of ceasing to use leaded gasoline. An alternative continuous Pb supply could be found in the brake pads wear of the vast number of these parts.

Ultimately, the spatial distribution of elemental concentrations of those mentioned above in the analyzed 482 SD samples is presented. The study will make it possible to estimate the incidence of pollution threatening residents' health in large cities in a fast way and the reason for it.

2 Study area

Mexico City (here thereafter referred to as CDMX) and its conurbated areas (upper and lower left panels in Fig. 1) make up the third-largest urban region in the world, accommodating more than 20 million inhabitants and more than 40,000 small and medium industries [15]. Forty million liters of fossil fuels are consumed daily on average, which results in tons of contaminants being emitted into the environment [16]. The northern area of the study site includes an important industrial center with a high-density population. The central area comprises the historical and socioeconomic center of the city, which is highly urban and commercial. The southern region is dominantly residential and commercial [15]. The predominant winds flow from the northeast to the southwest, where they come against the Sierra del Ajusco [17].

Fig. 1 Location map of Mexico City (upper and lower left panels) and sampling sites (right panel). Modified from [15]

3 Materials and methods

3.1 Street dust sampling

Samples analyzed in this study come from the SD sampling campaign reported in Aguilera et al. [15], in which 482 SD samples were collected with a systematic and homogenous distribution carried out in the dry March–April period of 2017. The separation between sampling points was ~ 1 km (right panel in Fig. 1), and the sampling area was confined to 1 m^2 over the streets along the sidewalks. Before collecting the SD, accessory components such as rocks, branches, and leaves were removed manually. SD was distributed into four mounds using a brush and deposited into labeled and georeferenced polyethylene bags. The samples were kept for two weeks in a cool, dry place away from direct sunlight and air to avoid mineral oxidation.

3.2 Sample preparation and XRF measurements

Because of the relatively high number of samples to be analyzed to cover large cities, traditional tablets preparation would enlarge time and effort significantly. Accordingly, sample preparation for XRF measurements was done using an alternative and faster sample preparation method, following the general guidelines described in the User Manual of the handheld *Genius 7000XRF* spectrometer [18]. Street dust samples (482) were fragmented and sieved using an agate mortar and a #10 plastic mesh, respectively. Two and a half grams of dried and powdered SD sample was placed in a *Teflon* cup with a $3.6\text{-}\mu\text{m}$ -thick Mylar (polyester) film lower window. Concentrations of eight different elements (V, Cr, Mn, Fe, Ni, Cu, Zn, and Pb) were determined using a *Skyray Instruments* handheld *Genius 7000XRF* spectrometer – 50 kV X-ray tube with a large-area beryllium-window silicon drift detector (SDD) at the Laboratorio

Universitario de Geofísica Ambiental (LUGA) of the Universidad Nacional Autónoma de México (UNAM) facilities. For each sample, three repetitions (with an integration time τ of 100 s each) were carried out. Thus, under the procedure above described, concentration results for each sample take no more than five minutes.

The internal reference material IGLs-1 (a lateritic soil sample from a set of eight geochemical reference materials [19]) was used for control purposes and measured systematically after 25 SD samples measurements. Once the elemental concentrations were determined, their precision and accuracy were estimated.

4 Data analysis

The precision of the measurements (estimated as the percent relative standard deviation (%RSD)) and its accuracy (%Acc, obtained by comparison of the mean concentration against the corresponding certified value) were determined for the different elements analyzed on the internal reference material IGLs-1. Additionally, a comparison between concentrations of some elements (Si, Ti, Al, Fe, Mn) and those obtained on the same samples using inductively coupled plasma optical emission spectrometry (ICP-OES) (F. Bautista-Zúñiga & A. Gogui-chashvili (Eds.), Atlas de metales pesados en los polvos y suelos urbanos de la Ciudad de México. In preparation) was carried out.

The contamination degree was estimated by the contamination factor (CF), defined as:

$$CF = \frac{C_n}{B_n}$$

where C_n is the concentration of the element (e.g., Pb, Zn, Cu, etc.) in the sample and B_n is the baseline value, as proposed by Morton-Bermea et al. [20].

The geoaccumulation index is defined as:

$$I_{geo} = \log_2 \frac{C_n}{1.5C_{ref}}$$

where C_n is the concentration of the element (e.g., Pb, Zn, Cu, etc.) in the sample and C_{ref} is the baseline value [21].

The spatial distribution of Pb, Zn, and Cu concentrations (mainly derived from industrial and traffic sources) was plotted using a geostatistical method, which consists of an exploratory data analyses (error detection), structural analyses or variogram, Kriging interpolation, and mapping. Details of the exploratory data analyses used can be consulted in Aguilera et al. [22] and references therein.

5 Results

Precision for the 14 elements analyzed from the reference material range between 1.2 and 15.9%, being Cr, Ni, K, and V, the less precise elements (Table 1). Without taking them into account, precision values range between 1.2 and 6.6%. Worth mentioning is that for a portable XRF spectrometer data to be considered adequately precise, the %RSD should not be higher than 20%. It is also worth noting that, by direct calculations of the precision values from the results reported in Lozano Santa Cruz [19] for the same reference material, the precision values for the same reference material obtained by a sequential WD-XRF (Siemens SRS 3000) spectrometer range in the interval of 0.1–5.3%.

In the case of accuracy, major and minor elements K, Ca, Ti, Mn, and Fe, along with Cr, were the least accurate (Table 1). Worth of note is that although V was one of the less precise elements determined, it was the most accurate (− 0.4%). A maximum under-/overestimation of less than 20% was obtained for the most accurate elements.

Linear fit regressions for Pb and Zn for all the SD samples, obtained with both methodologies (pXRF and ICP-OES), are shown in Fig. 2a, c. Correlation factors (R^2) of 0.725 and 0.923 were obtained for these elements, respectively. In the case of Pb, some abnormally high values (outlier)—coming mainly from the ICP-OES analysis—were identified. Corresponding *box and whiskers* plots for Pb and Zn (Fig. 2b, d) stand out the similar mean concentration values obtained by both methodologies for the first case (Pb), and a significant difference (close to 50%) for the second case (Zn). Worth mentioning is that ICP-OES results show more atypical values than those obtained by the pXRF analyzer. A summary of the results is presented in Table 2.

Lead concentrations of the 482 SD samples analyzed range in the interval of 16.7–1186.7 mg/kg, with an average value of 122.9 mg/kg. The Pb concentration average value obtained corresponds to almost one-third of the maximum permissible concentration (400 mg/kg) for residential/commercial usage allowed, according to SEMARNAT [23]. In the case of V, levels of the 474 SD samples analyzed range in the interval of 2–179 mg/kg, with a mean value of 57 mg/kg, which corresponds to ~ 73% of the maximum permissible concentration of 78 mg/kg allowed by the above-mentioned regulation. Unfortunately, no maximum allowable levels for Mn, Fe, Cu, and Zn are reported in SEMARNAT [23]. Table 3 summarizes the results of the statistical description carried out.

In comparison, the degree of contamination by Pb, estimated by the contamination factor (CF) using $B_n = 19$ mg/kg (after Morton-Bermea et al. [20]), ranges in

Table 1 Statistical parameters of the geological reference material IGLs-1 (lateritic soil) for 14 different elements obtained after each 25 SD samples set. %RSD: per cent relative standard deviation (precision); %ACC: accuracy, obtained by comparison of the mean concentration against the corresponding certified value. Concentration values reported here in mg/kg. Data in italics correspond to values which exceed 20%

	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Rb	Sr	Zr	Pb
Certified values	0.61 [%]	0.38 [%]	2.70 [%]	293 [mg/kg]	267 [mg/kg]	0.274 [%]	12.99 [%]	75 [mg/kg]	58 [mg/kg]	109 [mg/kg]	81 [mg/kg]	47 [mg/kg]	772 [mg/kg]	29 [mg/kg]
1	4169.8	2993.1	15,972.2	246.8	183.7	1981.1	90,646.5	86.2	64.5	129.2	76.7	40.4	627.3	28.0
2	4439.9	2969.6	15,969.4	312.1	196.1	2035.2	91,355.9	89.9	67.3	134.5	77.0	42.7	603.7	25.1
3	4033.4	3055.9	15,930.3	316.9	151.6	2004.6	90,500.6	82.3	62.8	116.6	82.5	40.0	629.3	23.0
4	5212.9	3078.9	16,041.8	354.0	157.0	1997.7	90,238.2	94.5	68.0	143.4	73.7	42.6	624.2	23.9
5	5277.1	2921.3	15,856.5	251.6	167.3	1988.2	90,688.8	58.2	79.6	141.0	80.1	37.6	617.1	25.9
6	3847.7	2866.0	15,583.8	196.3	184.8	1957.2	88,813.5	81.1	66.0	123.7	76.7	35.0	620.4	26.0
7	3741.5	3255.0	16,426.7	278.1	196.5	1967.8	91,343.8	97.7	70.9	133.3	80.9	33.5	619.2	27.7
8	4123.5	2967.0	16,131.7	298.5	187.0	1995.6	91,237.3	76.9	71.3	131.4	79.7	42.5	632.6	26.9
9	3015.6	2722.6	16,114.4	338.7	174.6	2009.1	91,025.3	79.8	78.1	133.1	78.6	36.4	612.0	28.4
10	4175.3	2774.3	15,885.0	284.6	225.5	1968.2	89,894.2	71.0	69.4	129.4	74.6	43.6	617.4	23.9
11	4507.0	3259.0	16,045.5	290.3	170.8	1977.8	90,405.3	80.3	67.3	131.6	74.9	38.1	630.8	25.3
12	3032.5	2880.5	15,888.2	263.1	194.6	1967.4	89,395.5	73.3	71.9	130.4	80.9	43.8	597.0	24.2
13	4351.0	3117.8	15,946.5	241.7	192.0	2010.2	91,015.9	84.1	62.1	127.9	81.7	35.1	619.2	24.9
14	4288.7	3210.0	16,026.5	290.5	143.2	1991.6	91,285.6	87.8	65.1	135.3	79.9	36.8	606.4	23.3
15	3193.2	2957.4	15,700.8	315.6	200.5	1970.5	90,157.8	80.7	56.7	145.5	83.5	39.4	617.1	25.4
16	4318.8	3233.4	16,263.9	391.6	166.1	2034.3	91,299.0	100.2	79.6	145.9	73.9	36.0	621.2	26.6
Mean =	4108.0	3016.4	15,986.5	291.9	180.7	1991.0	90,581.5	82.8	68.8	133.3	78.5	39.0	618.4	25.5
$\sigma =$	653.0	167.3	200.4	47.6	21.0	23.4	746.7	10.5	6.4	7.8	3.2	3.4	9.9	1.7
%RSD =	15.9	5.5	1.3	16.3	11.6	1.2	0.8	12.7	9.3	5.9	4.0	8.6	1.6	6.6
%ACC =	-32.7	-20.6	-40.8	-0.4	-32.3	-27.3	-30.3	10.3	18.6	22.3	-3.1	-17.1	-19.9	-12.0

Fig. 2 Linear fit regressions **a** and **c** and box and whiskers plots **b** and **d** for Pb and Zn

Table 2 Statistical description of Pb and Zn concentration in SD obtained with two different methodologies on the same set of samples: ICP-OES [15] and pXRF, this study. Concentration values in mg/kg

	Pb ICP-OES	Pb pXRF	Zn ICP-OES	Zn pXRF
# samples	479	475	479	474
Average	124.3	122.9	270.2	495.5
Standard deviation	107.5	114.9	209.2	396.1
Coefficient of variation [%]	86.4	93.4	77.4	80.0
Minimum	8.8	16.7	18.7	73.2
Maximum	1141.6	1186.7	2969.3	5539.9
Range	1132.8	1170.0	2950.6	5466.7
Standardized bias	34.1	26.6	52.6	52.0
Standardized kurtosis	110.0	76.5	275.2	264.7

the interval ~ 1 to 62, with a mean value of 6.5. According to Ihl et al. [24], a CF lower than 1 indicates insignificant contamination, between 1 and 3 indicates moderate contamination and between 3 and 6 indicates considerable contamination, while higher than 6 indicates high contamination (Fig. 3). Worth of note is that 62% of the SD samples show a $CF > 3$, while 30% of them exceed a $CF > 6$. Similarly, CF by Zn, using $B_n = 76$ mg/kg (after Morton-Bermea et al. [20]), ranges in the interval ~ 1 to 156, with a mean value of 6.8. For this element, 87% of the SD samples show a $CF > 3$, while 39% of them exceed a $CF > 6$. In the case of Cu ($B_n = 32$ mg/kg, after Morton-Bermea et al. [20]), an average CF value of 3.2 is obtained.

Likewise, the geoaccumulation index I_{geo} , using again $B_n = 19$ mg/kg (after Morton-Bermea et al. [20]), yields a Pb interval from -0.8 to 5.4 , with a mean value of 2.1, corresponding to moderately to strongly polluted ($I_{geo} = 2-3$). In the case of Cu ($B_n = 32$ mg/kg (after Morton-Bermea et al. [20])), an interval from -1.5 to 4.6 was

Table 3 Content of heavy metals in street dust samples of CDMX (mg/kg)

	V	Cr	Mn	Fe	Ni	Cu	Zn	Pb
Min =	2	16	300	15,984	22	21	73	17
Max =	179	667	1277	79,297	289	639	11,826	1187
Mean =	57	80	757	34,713	55	102	519	124
1 σ =	29	49	118	5489	26	77	653	117
VC (%) =	51	61	16	16	47	75	126	94

1 σ standard deviation, VC Variation coefficient **Fig. 3** Contamination factors (CF) for different elements in SD from CDMX based on mean elemental concentrations

obtained, with a mean value of 1.4, corresponding to moderately polluted ($I_{geo} = 1-2$).

The spatial distribution of Pb, Zn, Cu, and V concentrations in SD from CDMX is shown in Figs. 4, 5, 6, 7. These figures demonstrate that the central and (industrial) northern zone of CDMX presents the higher HM concentration values for Pb, Zn, and Cu. On the contrary, the southern area shows a higher V concentration (Fig. 7). While the high contamination Pb level for the central and northern zones could well be attributed to anthropic processes, the higher V concentration could be instead explained in terms of the geological characteristics and relief, as mentioned by Delgado-Carranza et al. [4].

The low Pb contents in the southern region of the city could be explained not only because of the lower number of industries and vehicular traffic but because of its extensive wooded areas. Pb-bearing particles could be gathered by the trees leaves instead of falling to the streets and sidewalks. Vanadium-bearing particles could be mainly of volcanic origin and are concentrated, due to the slope, drainage, and runoff, in the southern area, especially at the foothills of the Sierra Chichinautzin in the south, and the Sierra de la Cruces in the west of the city. The highest concentration of this element is observed around the Xaltepec volcano.

6 Discussion

The mean Pb concentration obtained in this survey well matches those from other previous investigations [4, 15, 20, 25], and the one brought using ICP-OES on the same samples (Table 4). In all cases, the mean Pb concentrations obtained are significantly underneath the maximum permissible levels (400 mg/kg) for residential/commercial usage allowed, according to SEMARNAT [23]. However, contamination factors point from considerable to high contamination for 62% and 30% of the street dust samples analyzed, respectively.

Moreover, a comparison between the results from the studies carried out during the last decade [4, 20, 24, 25] and those here reported suggests that no significant reduction in Pb concentration of SD has taken place for ten years despite three decades of ceasing to use leaded gasoline (Fig. 8). As well, a comparison between geoaccumulation indexes for Pb and Cu from this study against those obtained a decade ago shows a slight increment, despite three decades of stopping the use of leaded gasoline. Nevertheless, one must consider that CDMX's vehicular park doubled in 10 years: it grew 159% and increased to more than 9.5 million motorized units in circulation in 2015, according to FIMEVIC [26].

On the other hand, in a recent study carried out on street dust from the also densely populated and industrialized city of Monterrey, northern Mexico, Urrutia-Goyes et al. [13] found even higher Cu (167 mg/kg) and Pb (227 mg/kg) concentration values than in CDMX. Also, concentration values of the same order of magnitude are reported for other industrialized countries for the last decade [27, 28]. In a study of heavy metal in street dust from traditional markets in the southern area of South Korea, Kim et al. [27] report a similar mean Pb value of 128 mg/kg for a heavy traffic road, although even a higher mean Cu value of 353 mg/kg is observed. In the case of street dust of Baoji, NW China, Lu et al. [28] report mean concentration values of 433 and 123 mg/kg for Pb and Cu, respectively.

Therefore, concentration values above 100 mg/kg seem to be characteristic of densely populated and industrialized cities. These high concentration values seem to not

Fig. 4 Spatial distribution of Pb concentrations in SD from Mexico City

decrease with time, but also increase, as stated by Urrutia-Goyes et al. [13], "metals in street dust do not degrade and their concentration can only increase with time." This circumstance seems to be supported by the findings of Marrugo-Negrete et al. [29] "their subsistence can change from one media to another i.e., rain water can wash street dust to some degree and particles might be transported to nearby water streams".

However, it is hard to accept that large cities will never get rid of having high Pb contamination levels. Accordingly, an alternative continuous Pb supply should be found elsewhere, instead of gasoline, which, at least in Mexico, is Pb free. In a study of the distribution of heavy metals in road dust along an urban–rural gradient in Massachusetts carried out by Apaegyei et al. [11], a mean Pb concentration of 57 mg/kg in brake pads analyzed by XRF was reported, with a max value of up to 92 mg/kg. Taking into account this fact and considering the almost 10 million motor vehicles in CDMX, which use brake

pads, an alternative continuous Pb supply could be due to the pads wear from this considerable number of cars.

On the other hand, a decrease of 23% in the airborne lead levels due to the introduction of lead-free gasoline and the use of catalytic converters was reported by Cortez-Lugo et al. [30] in a study aimed to investigate the lead levels trend in the Mexico City metropolitan area atmosphere during the 1988–1998 period. In the same study, a cumulative decrease of 89% was reported by the gradual elimination of lead from gasoline.

However, one must note that atmospheric lead measurements—obtained through its extraction from particulate matter from 20 stations distributed in various areas of the CDMX metropolitan zone, located likely at a height over 2 m—represent "snapshots" of the daily Pb concentration. Air conditions are time and wind dependent and nonaccumulative. Instead, SD could vary seasonally and are accumulative.

Fig. 5 Spatial distribution of Zn concentrations in SD from Mexico City

7 Conclusions

Although Cr, Ni, K, and V are the less precise elements determined with the handheld instrument, its precision is in all cases < 20% and can be considered as adequately precise. An analysis time of ~ 5 min per sample would permit the elemental concentration determination of five hundred samples in somewhat more than a working week of 40 h, with the advantage of reusing the same material for additional analysis. The sample's low-amount requirements, simple nondestructive preparation procedure, and rapid elemental concentration determinations make portable XRF a promising geochemical

determination technique. These characteristics, together with an appropriate systematic and homogenous sampling distribution, make XRF measurements a useful proxy method for the rapid and economical evaluation of contamination by heavy metals.

Based on the results obtained in this and different investigations carried out through the last decade, no significant reduction in Pb concentration has taken place over the previous ten years in Mexico City despite three decades of stopping the use of leaded gasoline. An alternative continuous Pb supply could be found in the brake pads wear of this significant number of parts.

Fig. 6 Spatial distribution of Cu concentrations in SD from Mexico City

Fig. 7 Spatial distribution of V concentrations in SD from Mexico City

Table 4 Pb Concentrations in soils and SD of Mexico City obtained by different methodologies

Reference	Material	Technique	n	Average (mg/kg)	Min	Max
[20]	CDMX-soil	ICP-MS	135	112	5	452
[25]	CDMX-soil	XRF-WD	146	116	15	693
[24]	CDMX-soil	XRF-ED	89	163	20	654
Bautista-Zúñiga & Goguichaishvili	CDMX-SD	ICP-OES	481	128	9	1908
[4]	CDMX-SD	ED-XRF	89	206	17	610
This study	CDMX-SD	ED-pXRF	482	124	17	1187

(*) F. Bautista-Zúñiga & A. Goguichaishvili (Eds.), Atlas de metales pesados en los polvos y suelos urbanos de la Ciudad de México. In preparation.

Fig. 8 Mean lead concentration values in SD from CDMX obtained in different studies during the last decade. The dotted pink line corresponds to the average Pb concentration of 128 mg/kg

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Author contributions FB contributed to conceptualization. JM contributed to methodology. RC carried out the fieldwork. AA, JM, and RC performed formal analysis. JM contributed to writing—original draft preparation. JM, MS, and FB contributed to writing—review and editing. FB and AG were involved in funding acquisition. FB contributed resources. FB and AG were involved in supervision.

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Compliance with ethical standards

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Availability of data and material The datasets used and/or analyzed during the current study could be available from the corresponding author on reasonable request.

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