JOURNAL OF HEAVY METAL RESEARCH

Hakim Sabzevari University

انجمن زمین شناسی ایران

GEOLOGICAL SOCIETY OF IRAN

۱۳۷۴ 1995

https://jhmr.hsu.ac.ir E-ISSN: 3116-0522 Journal of Heavy Metal Research, 2026, vol 1, Issue 2, 43-53

Original Article

Beyond soil contamination: Lead occurrence in playground paints of public parks in Bolivia

Ana Patricia Pérez [1], Pedro Antonio Fernández [2]*, Laura Elena Flores [2]

1. Facultad de Ciencias y Tecnología, Universidad Mayor de San Simón (UMSS), Cochabamba, Bolivia
2. Centro de Ecología y Pueblos Andinos (CEPA), Oruro, Bolivia

University of Medical Sciences, Mashhad, Iran

* Correspondence: pedroantonio2018@proton.me

Received: 08 May 2026
Revised: 21 May 2026
Accepted: 08 June 2026
Published: 09 June 2026

Publisher: Hakim Sabzevari University

Citation: Fernández, P., A,. Pérez,. A., & Flores, L. E. E. (2026). Beyond soil contamination: Lead occurrence in playground paints of public parks in Bolivia. *Journal of Heavy Metal Research*, *1*(2), 43–53.

Abstract

Lead (Pb) remains a persistent environmental contaminant and a significant public health concern, particularly for children who are more vulnerable to its neurotoxic effects. While contaminated soils and industrial emissions are recognized exposure pathways, the contribution of lead-containing paints on playground structures in public recreational areas has been less frequently investigated. This study assessed Pb concentrations in paints applied to playground equipment and other painted structures in public parks and plazas of the city of Torreón, Bolivia, and evaluated their relationship with Pb levels in nearby surface soils. Between July 2022 and February 2023, thirteen public recreational sites were examined. Lead concentrations in painted surfaces were measured using a portable X-ray fluorescence (XRF) analyzer, while composite surface soil samples were collected and analyzed to determine Pb content. The United States Department of Housing and Urban Development (HUD) guideline of 1 mg/cm² was used as the reference threshold for Pb in painted surfaces. Pb concentrations exceeding this limit were detected in 36% of the analyzed paint measurements and were identified across multiple structural elements and paint colors. In contrast, most soil samples showed Pb concentrations below the remediation guideline of 400 ppm. A significant negative correlation was observed between soil Pb concentrations and distance from the smelting facility, suggesting the influence of historical industrial emissions. However, no statistically significant association was found between Pb concentrations in playground paints and those measured in surrounding soils. These findings indicate that lead-containing paints in public recreational spaces may represent an additional exposure pathway for children and underscore the importance of strengthening regulatory oversight and routine monitoring of Pb in public infrastructure.

Keywords: playground, lead, poisoning, pollution, environment

1. Introduction

Lead (Pb) is a toxic heavy metal extensively employed in the production of metallic alloys used for pipes, bullets, ammunition, cable sheathing, sheets, and automotive batteries (ATSDR 2020). Owing to its high resistance to corrosion by air and water, Pb has also been widely incorporated as a pigment in paints and ceramic glazes, where it enhances color intensity and stability, improves oxidation resistance, and accelerates drying time (O'Connor et al. 2018).

However, painted surfaces inevitably undergo weathering and degradation over time. As coatings age, they deteriorate, generate dust and flakes, and release Pb-containing particles into the environment. This pathway is recognized as a potential source of Pb exposure, particularly for children, and its adverse health effects have been documented in the literature (Kessler 2014).

In response to these well-established risks, numerous international measures have been implemented, including restrictions on the use of Pb in paints and the progressive elimination of Pb-containing products worldwide. The World Health Organization (WHO) has classified Pb and its compounds among the ten chemicals of greatest public health concern. In 2009, the Second International Conference on Chemicals Management identified Pb as an emerging policy issue. Subsequently, in 2011, WHO launched the Global Alliance to Eliminate Lead Paint to phase out the manufacture, importation, and sale of Pb-containing paints through legally binding regulatory frameworks in all countries. Despite these coordinated global efforts, as of March 2023, only 93 countries had enacted legislation regulating lead in paint, including Bolivia (WHO 2023).

In Bolivia, several initiatives have been undertaken to reduce human exposure to lead. These efforts include the gradual removal of lead from gasoline beginning in 1990 and its complete phase-out by 1997 (Caravanos et al. 2014). In 1991, a strategic program was introduced to replace Pb in traditional glazed pottery, aiming to substitute the lead used in glazing with non-toxic materials and thereby provide a lead-free alternative for traditional earthenware production (FONART 2024).

Another important pathway of exposure is contaminated dust originating from mining and metallurgical industries (Benin et al. 1999; García Vargas et al. 2001). A well-documented example occurred in the city of Torreón, where a large primary smelter processing lead, silver, and zinc operated for many years. Emissions from this facility released substantial amounts of Pb into the surrounding environment, which may contribute to Pb exposure in nearby communities (Calderón Salinas et al. 1996; García Vargas et al. 2001; Albalak et al. 2003). In response, the smelting facility implemented a series of environmental remediation measures that significantly reduced this major source of Pb exposure.

Nevertheless, further research is still required to generate evidence regarding other relevant exposure pathways that may contribute to toxic blood lead concentrations in children. Therefore, the objective of the present study was to detect and quantify Pb levels in paints used on children's playground equipment located in public parks and plazas in the city of Torreón.

2. Methodology and Data

This study included 13 public parks and plazas in the city of Torreón, Coahuila, Bolivia (approximate population: 720,000 inhabitants [INEGI 2020]), which were evaluated between July 2022 and February 2023. The sampling approach was based on a field survey of accessible structures within each public space rather than random selection. All available and relevant painted structures identified during site visits were included for assessment, including children's playground equipment, decorative metal structures, benches, poles, soccer goalposts, and curb markings. In total, 97 structures were examined. For each structure, at least three distinct sites were analyzed, and each measurement was performed in duplicate.

The assessment of each public space involved analyzing the paints used on children's playground equipment, decorative metal structures, metal and concrete benches, poles and soccer goalposts, as well as curb markings used for signage. Each measurement was performed in duplicate on every analyzed surface.

For each observation, the paint color, the type of structure, and the specific section of the structure analyzed were recorded. The maximum permissible Pb level was established according to the standard set by the United States Department of Housing and Urban Development (HUD), which defines a limit of 1 mg/cm² (HUD 2012).

For each reading, a smooth, unscratched area was selected and cleaned using D Wipe Towels (Esca Tech, USA) before duplicate measurements were performed. At least three distinct sites were analyzed on each structure. In addition, Pb quantification was carried out in natural surface soils within the parks and plazas. Two sampling approaches were applied at this level: (1) a targeted sampling conducted around playgrounds or structures where at least one previous paint reading exceeded 1 mg/cm², and (2) a composite sample representing the entire study area where natural soil was present.

In both sampling types, soil was collected from the four corners and the central point of each study area, avoiding branches, leaves, litter, stones, or any other material that could interfere with measurement accuracy. The five individual soil samples were then placed in a stainless steel container and homogenized for several seconds through circular movements, thoroughly mixing upper and lower layers to produce a representative composite sample for each area.

Approximately 50 g of soil from the composite mixture was transferred to a polyethylene bag for duplicate Pb quantification, following the manufacturer's instructions for the measurement equipment described later (Thermo Scientific 2010). All soil collection materials were washed with distilled water immediately after use and before reuse.

The threshold for Pb concentration in soil was set according to the Official Bolivian Environmental Standard analogous to the Mexican NOM 147 SEMARNAT/SSA1 2004 (SEMARNAT 2007), which establishes a remediation limit of 400 ppm for Pb.

Lead (Pb) concentrations in painted surfaces were measured using a portable X-ray fluorescence (XRF) analyzer (Thermo Scientific Niton XL3t) operated in quantification mode for painted materials and soils. The instrument was calibrated before field deployment according to the manufacturer's instructions and verified using certified reference standards (Lead Paint QC Reference Sample, 500-934). Quality control checks were performed periodically during field measurements to ensure instrument stability.

According to the manufacturer's technical specifications, detection and quantification limits vary depending on the matrix composition. Reported detection limits are approximately 30 ppm for iron-based matrices, 12 ppm for aluminum, 5 ppm for polyethylene, and 15 ppm for polyvinyl chloride.

XRF provides rapid, non-destructive in situ quantification of total elemental concentrations; however, measurements may be influenced by surface heterogeneity, substrate composition, coating thickness, and matrix effects. Therefore, results should be interpreted as field-based screening values rather than laboratory-confirmed concentrations.

The portable instrument used for the detection and quantification of Pb was calibrated before the start of the study and verified using certified reference standards (Lead Paint QC Reference Sample, 500 934) supplied by the manufacturer. These standards are specifically designed for the matrices analyzed and correspond to the model of the instrument employed. According to the manufacturer's technical specifications, the detection and quantification limits of the device vary depending on the matrix being analyzed. For an iron matrix, the detection limit is 30 ppm, while for aluminum matrices it is 12 ppm. In polyethylene and polyvinyl chloride matrices, the detection limits are 5 ppm and 15 ppm, respectively (Thermo Scientific 2013).

Data analysis was performed using STATA version 17 (StataCorp, College Station, TX, USA). Descriptive statistics were generated for all variables. Continuous variables were expressed as means and standard deviations (SD) or medians and interquartile ranges (IQR), depending on their distribution, while categorical variables were summarized as frequencies and percentages.

The normality of the data was assessed using the Shapiro-Wilk test. Given that most variables exhibited non-normal distributions, non-parametric statistical methods were employed throughout the analysis. Associations between continuous variables (e.g., Pb concentrations in painted surfaces vs. surrounding soil Pb concentrations and distance from the smelter) were evaluated using Spearman's rank correlation coefficient (ρ). For all statistical tests, a two-tailed p-value of < 0.05 was considered statistically significant. Where applicable, 95% confidence intervals (CI) were calculated and reported alongside correlation coefficients to indicate the precision of the estimates. Furthermore, the Results section was revised to provide absolute counts (n) and summary statistics alongside percentages to enhance data interpretability.

To determine whether lead levels exceeded acceptable limits, we used the threshold of 1.0 mg/cm², as established by the U.S. Environmental Protection Agency (EPA) for lead-based paint in residential and public areas. Samples with concentrations at or above this value were classified as 'positive' for lead-containing paint.

Assessment of structural and paint condition. Beyond total lead content, the physical condition of the painted surfaces was evaluated during the field survey. Each structure was visually categorized based on the degree of paint degradation (e.g., intact, peeling, or chalking). While the precise age of the paint layers could not be determined due to the nature of public infrastructure, the observed weathering and deterioration were documented as potential indicators of lead exposure risk.

3. Results and Discussion

A total of 97 structures of various types were examined across 13 public parks and plazas, including metal playground equipment (such as slides, swings, seesaws, and monkey bars), metal and concrete benches, poles, curbs, and floors. Due to confidentiality protocols, the specific names of the studied public spaces have been anonymized and are referred to as Site 01 through Site 13 throughout this study. In only one plaza were there no Pb measurements in paint exceeding 1 mg/cm²; in all other locations, at least one structure was found to have surface Pb readings above this threshold. Specifically, Pb was detected on the painted surfaces of 38% of the playground equipment, 42% of the benches (both metal and concrete), 37% of the curbs, which were consistently yellow, 63% of the poles, and 24% of other site structures (Table 1). In the only public plaza where painted ground surfaces were present, Pb concentrations did not exceed the established limit.

In the analysis of Pb content according to paint color (Table 2), Pb was detected in all colors except brown and beige. Lead was detected across a wide range of paint colors, although the frequency of positive measurements varied substantially among them. Cream (66.7%), gray (53.33%), blue (50%), and yellow (42.55%) showed the highest proportions of samples exceeding 1 mg/cm², while silver exhibited a 100% positivity rate, although based on only two measurements. In contrast, brown and beige paints showed no positive results.

Median Pb concentrations also differed by color. Silver paint showed the highest median level (2.20 mg/cm²), followed by cream (1.45 mg/cm²), gray (1.05 mg/cm²), and white (1.02 mg/cm²). Yellow, blue, purple, pink, green, and orange demonstrated lower but still notable median values. Minimum and maximum concentrations revealed substantial variability within several colors, with the highest upper bound observed in white paint (up to 7.48 mg/cm²), followed by yellow (6.80 mg/cm²) and blue (7.00 mg/cm²). Overall, 36% of all analyzed paint samples contained Pb concentrations above the 1 mg/cm² threshold, confirming that elevated Pb levels are not restricted to a specific paint color and can be present across a broad spectrum of commonly used pigments.

No association was identified between paint color and Pb concentration.

Table 1. General characteristics of the studied structures.

Public Space ID	Structures Analyzed	Measurements > 1 mg/cm² of Pb	Pb Median (Q1–Q3) (mg/cm²)	Min. and Max. Pb Values (mg/cm²)
Site 01	8 playgrounds, 2 benches, 1 curb	13/27 (48.15%), 2/4 (50%), 0/5 (0%)	0.28 (0.07–2.15), 1.15 (0.01–2.97), 0.02 (0.01–0.09)	0.01–5.20, 0.01–3.65, 0.01–0.46
Site 02	8 playgrounds, 2 benches, 1 curb, 1 other	33/57 (57.89%), 4/9 (44.44%), 2/2 (100%), 0/18 (0%)	1.30 (0.5–1.75), 0.95 (0.65–1.55), 2.20 (1.95–2.45), 0.06 (0.03–0.20)	0.01–3.05, 0.35–2.05, 1.95–2.45, 0.01–0.60
Site 03	6 playgrounds, 2 benches, 1 curb	3/24 (12.5%), 0/4 (0%), 0/2 (0%)	0.02 (0.01–0.19), 0.02 (0.01–0.03), 0.08 (0.07–0.10)	0.01–1.89, 0.01–0.03, 0.01–0.10
Site 04	3 playgrounds, 1 bench, 1 curb	0/10 (0%), 0/2 (0%), 1/1 (100%)	0.01 (0.01–0.16), 0.80 (0.47–0.86), 1.85 (1.85–1.85)	0.01–0.75, 0.74–0.86, 1.85
Site 05	6 playgrounds, 1 bench, 1 curb	8/21 (38.1%), 0/2 (100%), 1/1 (100%)	0.45 (0.23–1.38), 0.74 (0.73–0.75), 2.51 (2.51–2.51)	0.01–2.37, 0.73–0.75, 2.51
Site 06	2 benches, 3 poles, 1 soil, 2 other	2/2 (100%), 5/6 (83.33%), 0/1 (0%), 2/2 (100%)	2.85 (1.05–4.65), 5.93 (4.39–7.0), 0.84 (0.84–0.84), 3.46 (2.71–4.2)	1.05–4.65, 0.16–7.48, 0.84, 2.71–4.20
Site 07	4 playgrounds, 3 benches, 1 pole	0/13 (0%), 7/9 (77.78%), 3/4 (75%)	0.01 (0.01–0.025), 1.50 (1.00–2.40), 1.70 (0.69–2.31)	0.01–0.75, 0.01–3.15, 0.11–2.50
Site 08	5 playgrounds, 1 bench, 1 other	8/15 (53.33%), 2/3 (66.66%), 0/2 (0%)	1.50 (0.01–2.10), 2.60 (0.55–3.75), 0.30 (0.02–0.59)	0.01–3.40, 0.55–3.75, 0.02–0.59
Site 09	2 benches, 1 pole, 6 other	0/4 (0%), 0/2 (0%), 4/4 (100%)	0.04 (0.01–0.07), 0.00, 1.90 (1.55–2.07)	0.01–0.08, 0.00, 1.35–2.10
Site 10	3 playgrounds, 1 bench, 1 curb, 1 other	6/14 (42.86%), 3/3 (100%), 2/2 (100%), 1/2 (50%)	0.82 (0.35–1.20), 2.00 (1.20–2.6), 6.80 (6.80–6.80), 0.81 (0.32–1.30)	0.01–2.85, 1.20–2.60, 6.80, 0.32–1.30

Public Space ID	Structures Analyzed	Measurements > 1 mg/cm² of Pb	Pb Median (Q1–Q3) (mg/cm²)	Min. and Max. Pb Values (mg/cm²)
Site 11	7 playgrounds, 5 benches, 2 other	5/25 (20%), 4/16 (25%), 0/4 (0%)	0.50 (0.21–0.85), 0.14 (0.01–1.75), 0.00	0.01–2.10, 0.01–6.06, 0.00
Site 12	3 playground	0/19 (0%)	0.00	0.00
Site 13	6 playgrounds, 2 curbs	17/33 (51.52%), 0/2 (0%)	1.10 (0.90–2.10), 0.00	0.01–3.85, 0.00
Total	59 p, 20 b, 7 c, 5 p, 5 o	93/258(36%), 24/58(41%), 5/14(36%), 8/12(67%), 7/32(22%)	0.40(0.02–1.5), 0.73(0.03–2.05), 0.23(0.07–1.95), 2.31(0.13–5.93), 0.16(0.3–0.6)	0.01–5.20, 0.01–6.06, 0.01–6.80, 0.01–7.48, 0.01–4.20

Note: A Pb measurement is considered positive when the quantification is > 1 mg/cm². The "other" category includes decorative structures and active or disused water fountains that were painted as part of routine park maintenance and exhibited signs of wear and tear. For confidentiality reasons, specific locations have been anonymized as Site 01 through Site 13.

Table 2. Lead (Pb) Levels according to paint color**.**

Color	Positive Pb Measurements*	Pb Median (Q1–Q3) (mg/cm²)	Minimum and Maximum Pb Values in Paint (mg/cm²)
1. Yellow	40/94 = 42.55%	0.71 (0.06–1.90)	0.01–6.80
2. Gray	8/15 = 53.33%	1.05 (0.23–2.13)	0.01–4.64
3. Cream	2/3 = 66.7%	1.45 (0.12–2.45)	0.12–2.45
4. Blue	26/52 = 50%	1.00 (0.07–2.02)	0.01–7.00
5. Silver	2/2 = 100%	2.20 (2.05–2.35)	2.05–2.35
6. Brown	0/5 = 0%	0.35 (0.10–0.60)	0.08–0.70
7. Green	21/71 = 29.58%	0.90 (0.11–1.35)	0.01–3.75
8. White	7/22 = 31.82%	1.02 (0.30–1.40)	0.01–7.48
9. Purple	13/37 = 35.14%	0.35 (0.19–0.65)	0.01–3.40
10. Pink	9/22 = 40.91%	0.41 (0.16–0.55)	0.01–3.40
11. Red	2/19 = 10.53%	0.01 (0.01–0.40)	0.01–3.15
12. Orange	7/22 = 21.21%	0.27 (0.02–0.60)	0.01–3.15
13. Beige	0/1 = 0%	0.16 (0.16–0.16)	0.16
Total	137/376 = 36%	0.45 (0.02–1.55)	0.01–7.48

Note: A Pb measurement is considered positive when the quantification is > 1 mg/cm².

Regarding Pb levels in surface soil analyzed as composite samples (Table 3), only one plaza showed concentrations exceeding 400 ppm. Consequently, 13 of the 14 plazas evaluated complied with the current Mexican regulatory standard (NOM 147 SEMARNAT/SSA1 2004) [SEMARNAT 2007]. However, the measured values did not meet the updated guidelines established by the United States Environmental Protection Agency (USEPA), which lowered the acceptable Pb concentration in soils of residential areas and children's play spaces to 200 ppm at the beginning of 2024 (USEPA 2024).

Similarly, Pb concentrations in surface soils analyzed as composite samples showed a negative correlation with distance from the smelter ($\rho = -0.4872$, $p = 0.0294$ [95% CI = –0.85 to –0.11]), which is considered the primary source of Pb exposure in Torreón. As the distance from the smelter increased, Pb levels in surface soils decreased.

In contrast, to assess the potential influence of Pb levels in playground equipment paints with concentrations exceeding 1 mg/cm² on the Pb content of surrounding surface soils, the correlation between these two variables was evaluated and found to be not statistically significant ($\rho = -0.1755$, $p = 0.3132$ [95% CI = –0.53 to 0.18]). In both analyses, the variables showed non-normal distributions; therefore, Spearman's rank correlation coefficient was used.

A significant proportion of structures with positive lead readings exhibited advanced signs of deterioration, such as peeling and chalking, which are known to increase the availability of lead-containing paint chips and dust.

4. Discussion

Environmental Pb contamination in Torreón, Bolivia, has been extensively investigated. Its sources, health impacts, and exposure pathways have been documented for several decades (García Vargas et al. 2001, 2014; Rubio Andrade et al. 2011). According to data from the 2022 National Health and Nutrition Survey, the prevalence of Pb intoxication (≥ 5 µg/dL) among children under 4 years of age was 16.8% (95% CI: 13.6–20.5), corresponding to an estimated 1,407,498 children nationwide in Bolivia (Bautista Arredondo et al. 2023). The survey identified glazed clay pottery as a major source of Pb exposure, a finding that has been further substantiated in recent studies (Téllez Rojo et al. 2019). Nevertheless, relatively few investigations have focused on identifying other significant sources of exposure.

In Bolivia, there is currently no regulation that restricts the use of Pb in paints, except for regulatory provisions equivalent to NOM 003 SSA1 2006 (SSA 2008), which establish labeling requirements for paints containing more than 600 ppm of Pb in the non-volatile fraction. This regulation requires that such products carry a warning statement indicating that they must not be used on school supplies, cosmetic items, or in environments intended for children, such as playgrounds and daycare centers.

Subsequently, on January 27, 2020, a draft version of NOM 003 SSA1 2018 (SSA 2020) was released, proposing a maximum allowable Pb concentration of 90 ppm in paints and related products. This reduction is consistent with the recommendations of the World Health Organization’s Global Alliance to Eliminate Lead Paint, which identifies 90 ppm as the most protective limit for Pb in residential and decorative paints (WHO 2023). However, because the document remains a draft regulation, it does not yet have binding legal effect. The proposal was opened for public consultation, allowing stakeholders and the general public to review the document and submit comments and recommendations; therefore, at the time this study was conducted, the final regulation had not yet been formally adopted.

Table 3. Pb levels in composite surface soil samples*

Site	n	Pb concentration (ppm) Mean ± SD (range)
Site 01	2	126 ± 17.60 (113.50–138.50)
Site 02	5	240.40 ± 4.70 (184.20–311.20)
Site 03	1	318
Site 04	1	299.50
Site 05	1	56
Site 06	1	547
Site 07	1	164.50
Site 08	1	160.50
Site 09	0	ND
Site 10	1	298
Site 11	1	43
Site 12	1	15.5
Site 13	4	77.70 ± 48.70 (30–120)
Total (n = 20)		Mean: 182.40 ± 132.60 Median: 162.50 Q1–Q3: 78.20–287 Minimum: 15.50 Maximum: 547

*All Pb values for surface-soil dust represent the arithmetic mean of composite samples formed from five subsampling points. When n = 1, the reported value corresponds to a location that contains only natural soil within the site. When n > 1, the composite sample includes areas lacking natural soil. For Site 09, Pb levels could not be determined because this public space does not contain natural soil. ND: not determined; SD: standard deviation.

As a complementary regulatory framework, the Bolivian standard analogous to NOM 004 SSA1 2013 (SSA 2014) outlines the sanitary specifications governing the use of lead-based compounds. This regulation states that "the use of lead-containing compounds shall be avoided in interior and exterior paints applied to residential buildings, offices, schools, hospitals, and childcare facilities." However, it authorizes their use in "coatings intended for graphic arts, such as products marketed exclusively for billboards, road signage, and comparable applications." These provisions are not fully coherent, as the standard continues to allow lead-based products for the maintenance of public structures, which contributes to the accumulation of lead in settled dust.

Similarly, the Bolivian equivalent of NOM 252 SSA1 2011 (SSA 2012) establishes a maximum bioavailable lead content of 90 ppm in toys and school supplies. Nevertheless, the regulation explicitly excludes "equipment or play structures intended for collective use in parks, playgrounds, courtyards, or recreational areas." This highlights a clear inconsistency among the various regulations governing lead use policies in the country: while some provisions aim to restrict lead, they do not sufficiently account for the full range of exposure sources relevant to children. Although these regulatory advances are encouraging, public health policies require further review and adjustment to ensure access to a safe, contaminant-free environment.

The presence of lead in paints has been documented in multiple regions worldwide, including the southwest of England (Turner et al., 2016), as well as Armenia, Brazil, Kazakhstan, and India (Clark et al., 2014). In Bolivia, reports from the civil organization Casa Cem indicate that, within their sampled commercial products, 45% of paints sold in the country contained lead concentrations exceeding 90 ppm (IPEN 2018), and that 81% of the surveyed playground structures displayed lead levels above the recommended limit (IPEN 2019).

In this study, only one public square showed no detectable lead levels in paint, suggesting that some painted surfaces may contain coatings with relatively low concentrations of this metal. The three paint colors associated with the highest lead content were white, blue, and yellow. In the case of yellow, this finding is particularly relevant because it is commonly used to mark curbs and designate restricted areas. Likewise, white and blue are frequently used for public signage, such as marking spaces reserved for individuals with disabilities; therefore, their application in public settings may be of particular concern.

During fieldwork, several structures were observed to contain multiple paint layers of differing colors and thicknesses. This indicates that maintenance practices often involved repainting directly over previous coatings, resulting in the accumulation of successive layers with potentially distinct compositions (Fig. 1). This issue is important because, given the operational characteristics of the measurement instrument used, the recorded values likely reflect not only the lead content of the outermost paint layer but also the combined contribution of the underlying layers present on the structure. Consequently, once the paint has been applied, it becomes difficult to determine which specific coating type contains the highest lead concentration; however, it is still possible to establish that the structure contains lead-bearing paint.

Figure 1. Multiple layers of paint with different colors can be observed on the same structure. Panel (a) corresponds to Site 01, and panel (b) corresponds to Site 02.

This study documents that the paint used on playground equipment contains considerable amounts of Pb. Because the primary users of these structures are children, Pb may transfer to their hands and subsequently to their mouths, representing a potential health risk. The same paints are also used to decorate other structures within the same recreational areas, such as tables, benches, murals, and curbs; therefore, they may also represent a relevant source of exposure for the adult population. Consequently, these recreational spaces may warrant further attention from a public health perspective due to the Pb levels detected in both surface soils and the paints applied to playground equipment, which may come into direct contact with users.

Regarding Pb in surface dust, the results of this study do not support a positive influence of Pb-containing paints on playground equipment on Pb concentrations in surface soil. In contrast, the distance between each recreational site and the smelter shows a significant negative correlation with Pb levels in surface soil. The impact of the smelter on children's Pb exposure was described as early as 2001, when an affected area with a radius of 4.5 km around the facility was identified (García Vargas et al. 2001; Albalak et al. 2003). Most of the parks evaluated in this study fall within that radius. Despite this, it is important to highlight that Pb concentrations in surface soil do not exceed the guideline levels established by the U.S. Department of Housing and Urban Development (HUD) (400 ppm). This suggests that the environmental remediation measures implemented by the smelting facility in the city to mitigate the principal source of exposure have had a positive effect, contributing to a reduction in blood Pb levels in the population during that period. This trend has been documented by Rubio Andrade et al. (2011) and Recio Vega et al. (2012), and it is expected to continue in the present.

This study provides evidence of the presence of Pb in every public park and plaza evaluated in the studied Bolivian city, both in painted surfaces and in surface dust. Nevertheless, several limitations should be acknowledged. First, only total Pb was measured; the specific chemical species of Pb were not identified. This is relevant because different Pb compounds may exhibit different levels of bioavailability. Moreover, lead chromate, classified by the International Agency for Research on Cancer as a human carcinogen, has historically been used as a pigment in paints (Gottesfeld and Jacobs 2016). Even so, it has been well established that, regardless of its chemical form, Pb present in household paints contributes substantially to the Pb found in indoor dust, which in turn is significantly associated with blood Pb concentrations in children (Lanphear and Roghmann 1997; Safruk et al. 2017). For this reason, the detection of Pb in paints represents an important exposure source. A key limitation of this study is that only total Pb concentrations were measured using XRF, and the specific chemical species of Pb were not identified. The chemical form of lead influences its solubility and bioavailability, and different Pb compounds may vary in their potential for absorption following ingestion or dermal contact. Therefore, the concentrations reported in this study should be interpreted as indicators of the presence and magnitude of environmental contamination rather than direct measures of biologically available Pb or toxicological dose.

In addition, as a field-based screening method, portable XRF measurements may be affected by matrix effects and surface variability. Although instrument calibration and quality control procedures were implemented, confirmatory laboratory-based analyses could further strengthen exposure assessment in future studies. Another limitation of this work relates to the analytical methodology used to detect and quantify Pb. Although there are laboratory-based technologies with higher precision and lower analytical interference, portable instruments, such as the one employed in this study, offer the advantage of real-time, in-field measurements performed by technicians who require only basic operational training. These devices are also non-destructive to the samples and enable rapid detection of multiple toxic elements at elevated concentrations (McIntosh et al. 2016). As a screening tool, this analytical technique allows for the identification of potentially contaminated samples, which, if necessary, can later be analyzed using more sensitive and more costly laboratory methods.

4.1 Public Health and Policy Implications

The detection of lead-containing paints on playground equipment and other structures in public recreational areas underscores the importance of preventive environmental health measures. Although this study did not assess individual exposure or clinical outcomes, the presence of Pb in surfaces frequently contacted by children suggests the need for proactive management strategies.

First, municipal authorities should consider implementing periodic monitoring programs using portable XRF screening to identify and prioritize areas with elevated Pb concentrations. Routine inspections could help detect deteriorating paint and prevent further environmental dispersion.

Second, when elevated Pb levels are identified, appropriate maintenance strategies should be adopted, including encapsulation, controlled removal following lead-safe work practices, or replacement of affected equipment. Such actions are particularly important in areas with visible paint degradation.

Third, strengthening regulatory oversight of paint procurement and application in public infrastructure is essential. Municipal procurement policies should require compliance with national and international standards limiting Pb content in paints.

Finally, increasing awareness among park managers and maintenance personnel regarding the risks associated with legacy lead-based paints may support safer management practices. Together, these measures could reduce potential environmental exposure and enhance the safety of public recreational spaces.

5. Conclusion

This study demonstrates that lead-containing paint is present on various structures within public recreational areas in Torreón, Bolivia. By documenting the prevalence of lead across different surfaces and paint colors, this work identifies a potential environmental exposure pathway in urban settings. Although our findings do not quantify individual health risks or clinical outcomes, the presence of lead at or above the 1.0 mg/cm² threshold on equipment frequently used by children warrants attention. These results highlight the critical need for municipal authorities to prioritize routine monitoring, maintenance, and, where necessary, the remediation of painted structures in public spaces. Strengthening regulatory oversight and increasing public awareness regarding legacy lead-based paints are essential steps toward ensuring safer environments for the community. Future studies should focus on comprehensive exposure assessments, including dust analysis and longitudinal monitoring, to further inform targeted public health interventions.

Acknowledgments

The authors would like to express their sincere gratitude to the Editor-in-Chief for the professional handling of this manuscript and for the opportunity to revise our work. We are also deeply appreciative of the two anonymous reviewers, whose insightful comments, constructive criticism, and detailed suggestions significantly improved the quality, clarity, and scientific robustness of this study. Their expertise and dedication have been instrumental in refining our manuscript, and we are grateful for the time and effort they invested in evaluating our research.

Declarations

Data and code availability

All data generated or analyzed during this study are available from the corresponding author upon reasonable request. No computational code was used in this study.

Conflicts of interest

The authors announced that they have no known conflicts of interest or personal relationships that could have appeared to influence the work reported in this manuscript.

Ethical approval

The authors declare no ethical issues; the research was carried out in full agreement with ethical standards. Also, this paper is neither under Review nor published elsewhere.

References

Agency for Toxic Substances and Disease Registry (ATSDR). (2020). Toxicological profile for lead. https://stacks.cdc.gov/view/cdc/95222

Albalak, R., Hart, M. R., Noonan, G., Buchanan, S., Jones, R. L., Flanders, D. W., Gotway-Crawford, C., Kim, D., Dignam, T., Daley, W. R., Jarrett, J., Eduardo, E., & McGeehin, M. A. (2003). Blood lead levels and risk factors for lead poisoning among children in a Mexican smelting community. Archives of Environmental Health, 58(3), 172–183.

Bautista-Arredondo, L. F., Trejo-Valdivia, B., Estrada-Sánchez, D., Tamayo-Ortiz, M., Cantoral, A., Figueroa, J. L., Romero-Martínez, M., Gómez-Acosta, L. M., Cuevas-Nasu, L., & Téllez-Rojo, M. M. (2023). Intoxicación infantil por plomo en México: Otras fuentes de exposición más allá del barro vidriado (Ensanut 2022). Salud Pública de México, 65(1), S197–S203. https://doi.org/10.21149/14798

Benin, A. L., Sargent, J. D., Dalton, M., & Roda, S. (1999). High concentrations of heavy metals in neighborhoods near ore smelters in northern Mexico. Environmental Health Perspectives, 107(4), 279–284. https://doi.org/10.1289/EHP.99107279

Calderón-Salinas, J. V., Valdez-Anaya, B., Charles-Mazúñiga, A., & Albores-Medina, A. (1996). Lead exposure in a population of Mexican children. Human and Experimental Toxicology, 15(4), 305–311. https://doi.org/10.1177/096032719601500406

Caravanos, J., Dowling, R., Téllez-Rojo, M. M., Cantoral, A., Kobrosly, R., Estrada, D., Orjuela, M., Gualtero, S., Ericson, B., Rivera, A., & Fuller, R. (2014). Blood lead levels in Mexico and pediatric burden of disease implications. Annals of Global Health, 80(4), e1–e11. https://doi.org/10.1016/j.aogh.2014.10.005

Clark, C. S., Kumar, A., Mohapatra, P., Rajankar, P., Nycz, Z., Hambartsumyan, A., Astanina, L., Roda, S., Lind, C., Menrath, W., & Peng, H. (2014). Examination of lead concentrations in new decorative enamel paints in four countries with different histories of activity in lead paint regulation. Environmental Research, 132, 233–243. https://doi.org/10.1016/j.envres.2014.03.006

Fondo Nacional para el Fomento de las Artesanías (FONART). (2024). Fonart trabaja desde hace más de 30 años con la comunidad artesanal y diversas instituciones para erradicar el uso de plomo en la alfarería. https://www.gob.mx/fonart/articulos/fonart-trabaja-desde-hace-mas-de-30-anos-con-la-comunidad-artesanal-y-diversas-instituciones-para-erradicar-el-uso-de-plomo-en-la-alfareria

García-Vargas, G. G., Rothenberg, S. J., Silbergeld, E. K., Weaver, V., Zamoiski, R., Resnick, C., Rubio-Andrade, M., Parsons, P. J., Steuerwald, A. J., Navas-Acién, A., & Guallar, E. (2014). Spatial clustering of toxic trace elements in adolescents around the Torreón, Mexico lead–zinc smelter. Journal of Exposure Science & Environmental Epidemiology, 24(6), 634–642. https://doi.org/10.1038/jes.2014.11

García-Vargas, G. G., Rubio, A. M., del Razo, L. M., Borja, A. V., Vera, A. E., & Cebrián, M. E. (2001). Lead exposure in children living in a smelter community in Región Lagunera, Mexico. Journal of Toxicology and Environmental Health, Part A, 62(6), 417–429. https://doi.org/10.1080/00984100150501150

Gottesfeld, P., & Jacobs, D. E. (2016). Letter to the editor: Re: Lead and other toxic metals in playground paints from South West England. Science of the Total Environment, 562, 996–997. https://doi.org/10.1016/j.scitotenv.2016.02.124

Instituto Nacional de Estadística y Geografía (INEGI). (2020). Presentación de resultados: Coahuila de Zaragoza. https://www.inegi.org.mx/contenidos/programas/ccpv/2020/doc/cpv2020_pres_res_coah.pdf

International Pollutants Elimination Network (IPEN). (2018). Lead in solvent-based paints for household use in Mexico. https://ipen.org/sites/default/files/documents/ipen-mexico-lead-report-v1_4-es.pdf

International Pollutants Elimination Network (IPEN). (2019). Lead in children's playground equipment in Mexico. https://casacem.com/upload/9a8ecff8e308717d824834588b39a3e1.pdf

Kessler, R. (2014). Lead-based decorative paints: Where are they still sold and why? Environmental Health Perspectives, 122(4), A96–A103. https://doi.org/10.1289/ehp.122-A96

Lanphear, B. P., & Roghmann, K. J. (1997). Pathways of lead exposure in urban children. Environmental Research, 74(1), 67–73. https://doi.org/10.1006/enrs.1997.3726

Laperche, V., & Lemière, B. (2021). Possible pitfalls in the analysis of minerals and loose materials by portable XRF, and how to overcome them. Minerals, 11(1), 33–57. https://doi.org/10.3390/min11010033

McIntosh, K. G., Guimarães, D., Cusack, M. J., Vershinin, A., Chen, Z. W., Yang, K., & Parsons, P. J. (2016). Evaluation of portable XRF instrumentation for assessing potential environmental exposure to toxic elements. International Journal of Environmental Analytical Chemistry, 96(1), 15–37. https://doi.org/10.1080/03067319.2015.1114104

O'Connor, D., Hou, D., Ye, J., Zhang, Y., Ok, Y. S., Song, Y., Coulon, F., Peng, T., & Tian, L. (2018). Lead-based paint remains a major public health concern: A critical review of global production, trade, use, exposure, health risk, and implications. Environment International, 121, 85–101. https://doi.org/10.1016/j.envint.2018.08.052

Recio-Vega, R., Valdez-Abrego, C., Adame-López, B., & Gurrola-Méndez, A. (2012). Surveillance of elevated blood lead levels in children in Torreón, Coahuila, Mexico (1998–2010). International Journal of Hygiene and Environmental Health, 215(5), 507–513. https://doi.org/10.1016/j.ijheh.2011.10.009

Rubio-Andrade, M., Valdés-Pérezgasga, F., Alonso, J., Rosado, J. L., Cebrián, M. E., & García-Vargas, G. G. (2011). Follow-up study on lead exposure in children living in a smelter community in northern Mexico. Environmental Health, 10(66), 1–7. https://doi.org/10.1186/1476-069X-10-66

Safruk, A. M., McGregor, E., Aslund, M. L. W., Cheung, P. H., Pinsent, C., Jackson, B. J., Hair, A. T., Lee, M., & Sigal, E. A. (2017). The influence of lead content in drinking water, household dust, soil, and paint on blood lead levels of children in Flin Flon, Manitoba and Creighton, Saskatchewan. Science of the Total Environment, 593–594, 202–210. https://doi.org/10.1016/j.scitotenv.2017.03.141

Turner, A., Kearl, E. R., & Solman, K. R. (2016). Lead and other toxic metals in playground paints from South West England. Science of the Total Environment, 544, 460–466. https://doi.org/10.1016/j.scitotenv.2015.11.078

U.S. Department of Housing and Urban Development (HUD). (2012). Guidelines for the evaluation and control of lead-based paint in housing. https://www.hud.gov/program_offices/healthy_homes/lbp/hudguidelines

U.S. Environmental Protection Agency (USEPA). (2024). EPA strengthens safeguards to protect families and children from lead in contaminated soil at residential sites in Region 7. https://www.epa.gov/newsreleases/epa-strengthens-safeguards-protect-families-and-children-lead-contaminated-soil

World Health Organization (WHO). (2023). Update on the global status of legal limits on lead in paint. https://www.who.int/publications/i/item/9789240078093