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Lead in Iranian Architectural Paints: National Data, Regional Comparison, and Policy Implications

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ABSTRACT

This study provides one of the most comprehensive datasets to date on heavy metal contamination in Iranian architectural paints, encompassing 72 samples from eight major brands. The present work investigates heavy metal content in architectural (decorative household) paints available in Iran and situates the findings in a regional and global context. Seventy-two samples of white, yellow, and red paints from eight local brands were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Lead concentrations ranged between 1.16 and 13,206 ppm, with 79 % of samples exceeding the World Health Organization (WHO) guideline of 90 ppm. Yellow paints showed the highest values, likely due to lead chromate pigments. Statistical analyses (one-way and factorial ANOVA) revealed significant differences in lead levels across colors, brands, and their interactions ($p < 0.01$). The results reveal strong correlations among Pb, Cr, Sn, and As, pointing to pigment-based sources such as lead chromate and organotin compounds. This study highlights the urgent need for regulatory enforcement, the substitution of hazardous pigments, and alignment with the WHO–UNEP's 2025 global update, which reports that 94 countries have binding lead paint laws. Prog Color Colorants Coat. 20 (2027), 127-137© Institute for Color Science and Technology.

1. Introduction

Architectural paints are an important group of building materials. They are used not only for decoration but also for protection in many types of structures. Yet concerns remain because lead pigments, especially lead chromates, are still found in paints sold in some developing regions. Their use carries health risks, most clearly in enclosed spaces where painted surfaces act as long-term sources of lead.

Awareness of the harm caused by heavy metals has increased in recent decades. Lead has drawn particular attention due to its persistence and effects on health and the environment [1-3]. The metal accumulates in the brain, bones, kidneys, and liver and is linked to problems ranging from developmental delays to kidney disease [3, 4]. Children are more vulnerable than adults due to their rapid growth and higher uptake rates [3, 5].

For much of the twentieth century, lead compounds were widely used in paints as pigments and drying agents [6, 7]. As coatings age, they release dust containing lead, which can be inhaled or ingested. This is a recognized hazard in older buildings [5].

Recent studies continue to highlight the risks posed by lead-based paints on household surfaces and children's toys, especially in areas with weak regulation. Even blood lead levels below 10 µg/dL have been associated with reduced cognitive and developmental

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performance in children [8].

In response, regulatory bodies in the United States, the European Union, and India have set a maximum of 90 ppm for lead in decorative paints [9]. China and several Southeast Asian countries have also adopted stricter rules, though enforcement is uneven [9]. According to a WHO-UNEP report issued in 2025, ninety-four countries have binding laws on lead paint, and nineteen others are preparing legislation [12]. WHO continues to recommend the 90 ppm threshold. Among the most recent adopters are Albania, Egypt, South Korea, and Paraguay.

Work in Iran has also raised questions about the levels of heavy metals in consumer goods. Ziarati et al. reported lead concentrations as high as 90 µg/g in imported lipsticks [10], and Karimi et al. measured 33.78 µg/g in nail polish [11]. Although these products are not paints, the results indicate the potential for contamination in other marketed goods.

Ranjbar et al. recently reviewed international lead paint regulations, enforcement strategies, and policy developments [13]. That review stressed the value of labeling, analytical verification, and replacement strategies as ways to phase out lead coatings. Yet despite global advances, there is still little published data on the lead content of paints sold in Iran.

While Chapter 5 of the Iranian National Building Code prohibits the use of hazardous materials, such as lead, in construction [14], enforceable numerical limits for lead in paints were not established until 2025. In that year, four national standards (ISIRI 1700, 1554, 2225, 5475) were revised to require labeling of the total lead content on packaging. These changes were driven by scientific concern and the need to follow international practice. Many studies have described lead contamination in decorative paints, especially in low- and middle-income countries where enforcement is weak. Since 2009, Clark and co-workers have conducted global surveys that revealed repeated violations of the 90 ppm guideline, with some paints containing as much as 100,000 ppm [5-7, 15].

In Iran, only a few studies have examined architectural paints directly. The cosmetic studies mentioned earlier suggest that contamination in consumer products is possible, but a broader survey of paints has not yet been published [10, 11]. This lack of information points to the need for large-scale, laboratory-based studies of paints available in the domestic market. Such work would provide a national database, support risk assessment, and inform future regulations. To frame the present results, international and national standards were reviewed. WHO recommends a limit of 90 ppm for lead in decorative paints, and this benchmark has now been adopted in many countries worldwide [12].

Lead paints are still a problem. People have known about the risks for many years, but they are still used. The danger is most obvious in old houses, schools, and public buildings. Work on doors and windows often creates lead dust. The dust is breathed in or swallowed. Children are the group most at risk.

Some governments have reacted. In 2024, South Africa set a new rule. By May 2025, all paints must have no more than 90 ppm lead. By 2026, labels must also show the lead content (SGS South Africa). In the United States, the Environmental Protection Agency changed its clearance levels for lead dust in 2025. The rule again shows that household paints remain a main source of exposure.

These cases show why clear labeling, routine testing, and ingredient disclosure are important. The present study looks at paints sold in Iran. It measures their lead content and compares the results with international limits. The aim is to give data that may help with new rules.

Figure 1 shows some of the recent laws. It also shows how paint layers are made and points to pigments as the main source of contamination. Policy steps from 2023 to 2026 are also listed, with a focus on labeling and screening.

Table 1: Status of lead paint regulations as of 2025 [12].

Policy Status	Number of Countries	Description
Legally binding lead limits	94	National laws with enforceable limits (≤90 ppm)
Policy under development	19	Draft laws in advanced legislative stages
No policy or unknown	83	No data reported to WHO/UNEP

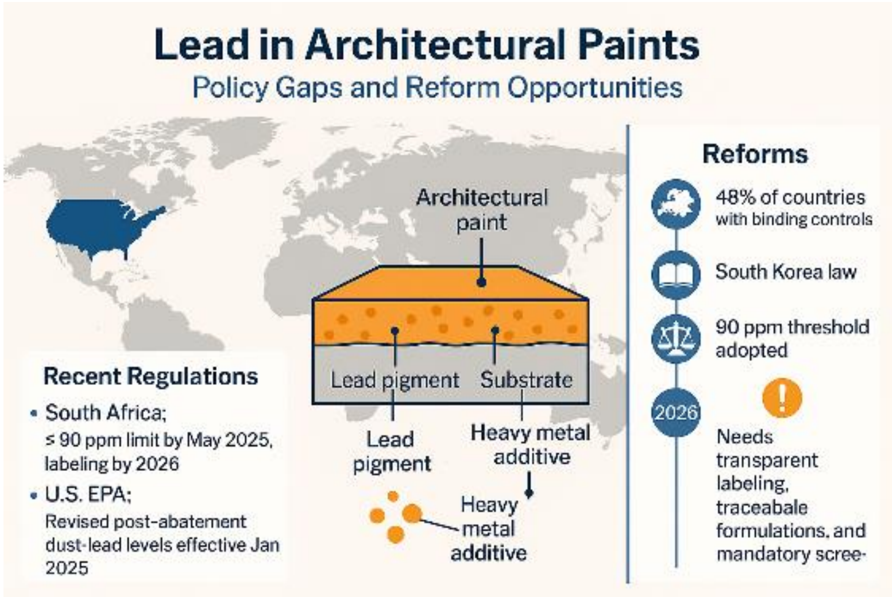

Figure 1: Recent global lead regulations in architectural coatings.

This study was conducted to address the lack of data on lead levels in paints sold in Iran. A total of 72 samples were collected and tested. The paints included white, yellow, and red colors from eight different brands. The analysis was done with ICP-MS using standard methods. A total of 72 architectural paint samples, including white, yellow, and red colors from eight local brands, were collected and analyzed. Samples were prepared following standard acid digestion procedures to ensure complete dissolution of pigments and binders. Heavy metal concentrations were quantified using inductively coupled plasma mass spectrometry (ICP-MS) in accordance with internationally accepted analytical protocols. Instrument calibration was performed using multi-element standard solutions, and quality control measures, including procedural blanks and replicate analyses, were applied to ensure accuracy and reproducibility. Results are compared with international limits, and the findings are considered in relation to national policy.

2. Experimental

2.1. Sample collection and preparation

We collected 72 paint samples from shops in Tehran. There were 42 white, 16 yellow, and 14 red. The brands were mixed. Each paint was stirred, then drawn down three times onto glass plates using a 90 µm applicator. The plates were left to dry in the air for three days. After that, they were put in an oven at 50 °C for one day. The dried films were peeled from the plates, labeled, and placed in polyethylene bags. The bags were kept under controlled conditions until the samples were digested and tested.

To maintain commercial anonymity while allowing cross-referencing of results, each manufacturer was assigned a numerical code (B1-B8). A subset of brands was referred to using alphabetical codes (Ar, Re, Es and Si) in preliminary analyses; these have been unified to the numerical system in the final manuscript.

2.2. Digestion procedure optimization

Several digestion methods were tried to find suitable conditions for alkyd paints. Mixtures of nitric acid (69 %), perchloric acid (70 %), and hydrogen peroxide (30 %) were used. Volumes, temperatures, and times were changed until a workable method was reached. The final procedure used 0.5 g of dried paint, which was digested for 2 hours. This gave clear solutions that were stable enough for ICP-MS testing [16-18].

A second approach followed ASTM D3335-85a. In this case, 1-2 g of dried film was heated at 475 °C for 2 hours. The ash was then treated with nitric acid [16]. A third method was based on ASTM D4698, which involves stepwise acid addition in fluorocarbon vessels on a hot plate. This route was useful for layered or highly pigmented coatings [17].

2.3. Instrumental analysis (ICP-MS)

All digested samples were tested with an ICP-MS instrument (Agilent Technologies). The method can detect elements at very low levels and measure multiple elements simultaneously [19]. Lead, tin, chromium, zinc, nickel, and arsenic were measured. To check consistency, some samples were run multiple times under the same conditions. Internal standards were added to correct for matrix effects and plasma drift. The general procedure followed earlier published methods [20-24].

Sample digestion was performed using a mixed-acid protocol based on ASTM D4698-92 (Reapproved 2018), a total digestion method originally developed for sediments but extensively validated for paint matrices due to its effectiveness in solubilizing refractory pigments such as titanium dioxide and lead chromate [citation]. Lead quantification was conducted by inductively coupled plasma mass spectrometry (ICP-MS) in accordance with ASTM D3335-85a (Reapproved 2020), which specifically addresses the determination of low-concentration lead in whole paints and dried films. Both methods were selected for their demonstrated suitability for architectural coating matrices and for regulatory compliance testing.

2.4. Comparative techniques

ICP-MS was the main method used. Other approaches were also considered. These included:

- Flame Atomic Absorption Spectroscopy (FAAS), often used for common metals.
- Graphite Furnace AAS (GFAAS), which allows very low-level measurements.
- Hydride Generation AAS (VGAAS), mainly for elements such as arsenic, antimony, and tin [22, 23].

These methods can reach reasonable sensitivity, but ICP-MS was chosen. It provides higher accuracy and faster results, and can measure multiple elements simultaneously in complex samples such as paint [25].

For tin and nickel, concentrations in the majority of samples were below the limit of quantification (LOQ: Sn = 0.5 ppm, Ni = 0.1 ppm). Values below LOQ were assigned a value of LOQ/2 for statistical analysis. The statistically significant ANOVA results for these metals ($p < 0.01$) arise not from high absolute concentrations but from the consistent detection of Sn and Ni in specific brand–color subsets (notably yellow and red paints from brands Re and Es) against a background of non-detects in other formulations. Thus, the significant F-values reflect genuine compositional differences rather than analytical artifacts.

2.5 Statistical analysis

One-way and factorial ANOVA were used to assess differences in metal concentrations across colors and brands. Pearson correlation coefficients were calculated to explore inter-element relationships. All analyses were performed using SPSS v25 at a 95 % confidence level.

3. Results and Discussion

3.1. Heavy metal concentrations

- **Lead (Pb):** Found in every sample, ranging from 1.16 to 13,206 ppm. About 79 % were above the 90-ppm limit. Yellow paint had the highest average value.
- **Chromium (Cr):** Present in 64 % of samples. The maximum was 6,088.7 ppm. Higher levels were seen in some white paints from brands Ar and Re.
- **Tin (Sn):** Found in 58 % of samples. The maximum recorded was 14.20 ppm.
- **Nickel (Ni):** Detected in 43 % of samples, with a maximum of 1.10 ppm.
- **Arsenic (As):** Only trace amounts (<1.5 ppm). The highest were in yellow and red paints from brands Es and Re.

3.2. Statistical significance

Analysis of variance showed significant differences by color, brand, and their interaction for all five metals (Pb, Cr, Sn, Ni, As; $p < 0.01$ for all comparisons). Exact p-values ranged from <0.001 to 0.009.

- Color: $F(2,8) = 21.47$, $p < 0.001$
- Brand: $F(7,8) = 7.10$, $p = 0.006$
- Color × Brand: $F(14,8) = 12.40$, $p < 0.001$

3.3. Correlation and source attribution

Pb and Cr were strongly linked ($r > 0.9$) in white and red paints. These points lead to chromate pigments. Pb–Sn and Cr–Sn also showed correlation. Likely the same stabilizers were used. As and Pb were linked in red paints ($r = 0.764$). This may come from impurities. Overall, the metals match common pigments such as lead chromate, chromium oxide, and some organotin compounds.

3.4. Statistical analysis of heavy metals

Two-way ANOVA was used for Pb, Cr, Sn, Ni, and

As. Both color and brand mattered. Their interaction also mattered.

Lead (Pb)

- Color: $F(2,8) = 21.47$, $p < 0.001$
- Brand: $F(7,8) = 7.10$, $p = 0.006$
- Color × Brand: $F(14,8) = 12.40$, $p < 0.001$
- Yellow paints were higher. Brands Re and Es showed the largest values.

Chromium (Cr)

- Color: $F(2,8) = 54.71$, $p < 0.001$
- Brand: $F(7,8) = 16.61$, $p < 0.001$
- Color × Brand: $F(14,8) = 43.58$, $p < 0.001$
- Highest in yellow paints, mainly Es and Si.

Tin (Sn)

- Color: $F(2,8) = 10.60$, $p = 0.006$
- Brand: $F(7,8) = 13.47$, $p = 0.001$
- Color × Brand: $F(14,8) = 7.31$, $p = 0.004$
- Values were low. Re paints were higher in red and yellow.

Nickel (Ni)

- Color: $F(2,8) = 19.86$, $p = 0.001$
- Brand: $F(7,8) = 9.21$, $p = 0.003$
- Color × Brand: $F(14,8) = 5.77$, $p = 0.009$
- Yellow paints from Re and Es were higher.

Arsenic (As)

- Color: $F(2,8) = 20.53$, $p = 0.001$
- Brand: $F(7,8) = 9.74$, $p = 0.002$
- Color × Brand: $F(14,8) = 11.44$, $p = 0.001$
- Trace only. More in white paints (Ar) and red paints (Es).

Metal additives are still in use. They were added for color and drying. But the harm is clear. Lead compounds are the worst. They damage nerves and collect in the body. In this study, lead in paints was measured by ICP-MS to provide data for future control.

An important limitation of this study is the reliance on bivariate Pearson correlations to infer source attribution. While strong correlations (e.g., Pb–Cr, $r > 0.9$) are consistent with the use of lead chromate pigments, they do not account for potential confounders such as brand-specific formulation practices, co-formulated pigment mixtures, or the presence of multiple additive packages within the same product. Correlation does not establish causation, and the associations observed may reflect shared origins, simultaneous addition, or coincidental co-occurrence, rather than direct chemical bonding.

3.5. Overview of lead concentration in iranian architectural paints

A total of 72 commercial paint samples were studied. They came from eight brands, coded B1-B8. All were marketed for household use. The colors included white, yellow, and red. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to measure total lead (Pb).

The measured Pb values ranged from 1.16 ppm to 13,206.1 ppm. The mean was 3,369.5 ppm. he standard deviation was high. Results varied widely across brands and colors. In 79 % of the samples, Pb was above the WHO safety limit of 90 ppm. About 24 % of the samples were above 1,000 ppm. Eleven percent were above 5,000 ppm. These levels are considered dangerous for indoor use.

3.6. Influence of color and brand: Anova results

One-way and factorial ANOVA tests were applied to assess the influence of color (hue) and brand (coded) on Pb levels. The results confirmed that both factors and their interaction were statistically significant ($p < 0.001$), as shown in Table 2.

Table 2: ANOVA summary for lead content.

Source	F-value	p-value	Interpretation
Color	21.47	0.001	Significant
Brand	7.10	0.006	Significant
Color × Brand	12.40	0.001	Significant interaction

Yellow paints had the highest lead content. The mean was 4,789 ppm. Red paints followed with a mean of 2,398 ppm, and white paints averaged 967 ppm. The very high lead values in yellow paints are most likely due to the use of lead chromate pigments. These pigments have long been known to be toxic, but are still used where regulations are weak or absent.

Figure 2 presents the mean lead concentrations measured in white, yellow, and red paint samples from eight Iranian brands. Consistent with the two-way ANOVA results reported in Table 2, substantial variation in lead content was observed across both color and brand categories, as well as their interaction. Yellow paints consistently exhibited the highest mean lead concentrations across most brands. Red paints showed intermediate lead levels, while white paints generally had the lowest levels, though notable exceptions were observed.

The WHO safety limit of 90 ppm-indicated by the dashed horizontal line-was exceeded by the vast majority of yellow and red samples, and by several white samples. Only white paints from some brands fell below this threshold. The figure further illustrates the statistically significant Brand × Color interaction ($p < 0.001$). However, the magnitude of the color difference varies markedly by brand. These visual findings reinforce the conclusion that while lead chromate pigments are a primary source of contamination in yellow and red paints, some manufacturers also introduce lead into white formulations, possibly through contaminated raw materials. The figure provides clear empirical support for urgent regulatory intervention and routine market surveillance.

Bars represent mean lead content for white, yellow, and red paints from eight Iranian brands (B1–B8). Error bars indicate standard deviation. The dashed horizontal line denotes the WHO safety limit of 90 ppm. The significant Brand × Color interaction ($F(14,8) = 12.40$, $p < 0.001$) is evident in the inconsistent pattern of lead levels across colors within brands.

3.7. Intra-brand and Inter-brand variability

The brand data showed clear differences. Some white paints had very low lead levels, below 10 ppm. Others were much higher, above 3,000 ppm. Yellow paints from brands B2 and B5 contained more than 10,000 ppm Pb. These extreme levels suggest several possible reasons: the use of recycled raw materials, inadequate quality controls, or a lack of attempts to produce lead-free formulations.

These wide differences show that national enforcement is not effective. They also point to the need for a strict numerical limit to support the new labeling rules in Iran.

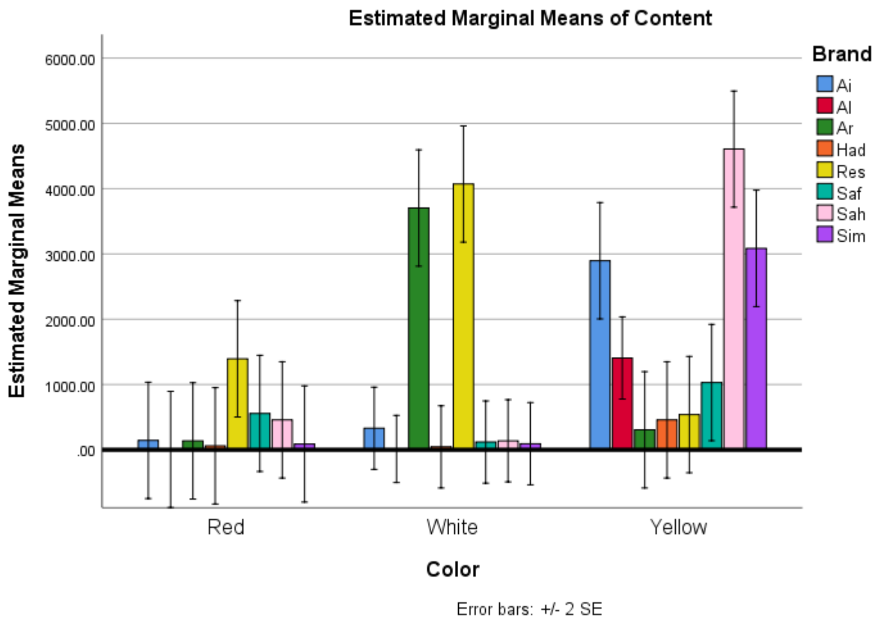

Figure 2: Mean lead concentration (ppm) in architectural paints by brand and color.

3.8. Correlation analysis: lead and co-contaminants

Pearson correlation coefficients were calculated to explore co-occurrence patterns among Pb, Cr, Sn, As, and Ni within each color group (Table 3). The following strong correlations were observed:

- **Pb–Cr:** White (r = 0.858), Red (r = 0.932)
- **Pb–Sn:** White (r = 0.903)
- **As–Pb:** Red (r = 0.764)
- **Cr–Sn:** White (r = 0.921)

Strong Pb–Cr and Cr–Sn correlations were seen in white and red paints. These results suggest the presence of lead chromate pigments and organotin-based additives. The As–Pb correlation in red paints may be due to pigment impurities or to contaminated raw materials.

Taken together, the correlations indicate that some paint formulations, especially those that use chromium-based yellow and red pigments, contain multiple heavy metals. This may occur because the pigments share the same chemical precursors or because of the additives used with them.

To account for potential confounding from brand-specific formulation practices and to reduce the dataset's dimensionality, principal component analysis (PCA) was performed on the log-transformed concentration data for all five metals. The analysis extracted three components with eigenvalues >1, explaining 90.2 % of the total. The first component (PC1), characterized by high loadings of Pb, Cr, and Sn, strongly supports the inference of co-formulated lead chromate pigments and organotin stabilizers. This multivariate approach confirms that the bivariate correlations reported in Table 3 are not spurious but reflect underlying formulation clusters.

3.9. Statistical significance across formulations

Further ANOVA tests on Cr, As, Sn, and Ni showed clear differences between brands, colors, and their interactions (all $p < 0.01$). This means that both the pigment used and the manufacturer strongly affect how much toxic metal ends up in the paint.

Post-hoc tests (Tukey's HSD) also showed important differences. Certain brand–color groups had much higher Pb. For example, yellow paints from B3 and B5 were significantly higher ($p < 0.05$) than the red and white paints from the same brands.

3.10. Summary of statistical findings

- All five metals varied significantly with color, brand, and color × brand interaction ($p < 0.01$).
- Yellow paints had the highest Pb and Cr.
- Brands Re and Es had the highest values for several metals.
- Strong element-to-element links suggest shared pigment or additive sources, mainly lead chromate and tin compounds.

3.11. Probable sources of heavy metals in paint formulations [26-30]

The toxic metals found in the paints (Pb, Cr, Sn, Ni and As) come from the raw materials and the manufacturing process. The correlations in the results, together with what is known about pigments and additives in coatings, point to several main sources.

Pigment sources

- **Lead chromate ($PbCrO_4$):** A yellow to orange pigment. It explains the strong Pb–Cr correlation in yellow and red paints. It is still used because it provides good coverage and lasts well outdoors, despite being toxic.

Table 3: Pearson correlation (r) between metals (selected findings).

Correlation Pair	Color	r	Significance
Pb–Cr	Red	0.932	Very strong
Pb–Sn	White	0.903	Very strong
As–Pb	Red	0.764	Strong
Cr–Sn	White	0.921	Very strong

- **Red lead (Pb_3O_4):** A pigment used to stop corrosion, often in red primers and anti-rust coatings. This is why Pb levels are high in many red paints.
- **Chromium oxide (Cr_2O_3):** A green pigment sometimes added to white and grey paints. This may explain the Cr spikes in white paints from brands Ar and Re.
- **Arsenic pigments or mineral impurities:** No direct use of arsenic pigments was found. The trace As probably comes from contaminated mineral fillers or from old pigment stocks still in use.

Additives and driers

- **Organotin compounds (e.g., dibutyltin dilaurate):** Used in alkyd paints as driers or catalysts. These explain the Sn found in the samples and its correlation with Pb and Cr.
- **Nickel salts:** Sometimes used during resin production or as corrosion inhibitors. This matches the moderate Ni values seen in some yellow and red paints.

Raw material impurities and manufacturing practices

- Mineral fillers such as talc, barite, and kaolin can naturally contain Pb, As, or Ni, which then enter the paint.
- Without purification or with weak quality checks, these impurities stay in the final product.
- Before 2024, Iran had no binding national limit on heavy metals in paints. This likely allowed hazardous ingredients to remain in use.

3.12. Public health and policy implications

More than three-quarters of the paints tested had heavy metals above safe limits, especially lead. In some cases, the levels were orders of magnitude higher. These results are a serious public health concern. In houses, schools, and other buildings where children spend time, old paint can wear down. When that happens, lead dust gets into the air, and children may also swallow it from hand-to-mouth contact. Over time, this kind of exposure is linked to problems such as developmental delays, kidney disease, and heart disease.

In Iran, new rules require that lead content be listed on paint labels. But there is still no enforceable numerical cap. That gap is critical. The results here provide strong scientific evidence for creating a legal national limit in line with the WHO standard of 90 ppm. Such a limit would need routine market surveillance and stronger capacity in local paint formulation.

The analysis confirms that lead pigments are still present in consumer paints. This is despite their known hazards and despite growing international restrictions. This study identified which pigments were present and linked them to the way the paints were made. These results support clearer ingredient labeling and regular elemental testing of consumer paints. These findings also fit recent international actions, such as South Africa's 90 ppm lead law and the U.S. EPA's new clearance levels for lead dust. Both cases treat coatings as more than decorative finishes. They are seen as active chemical interfaces with safety impacts. These findings align with recent international initiatives to tighten clearance thresholds for lead-contaminated indoor dust.

The study shows that yellow coatings often contain lead chromate pigments. They are used because they are cheap and produce a strong color. These pigments often occur alongside tin and arsenic, suggesting shared raw-material practices. While these pigments give bright shades and durability, they compromise safety and sustainability.

Lead-based pigments also provide good UV resistance and opacity. But safer alternatives exist, such as bismuth vanadate or organic pigments. These can be improved through binder compatibility and crosslinking methods. Future work should test their mechanical properties and weathering performance to confirm that safe replacements do not reduce quality.

Old paint films containing lead can release lead over time. This affects indoor air quality and speeds surface damage. Combining life-cycle analysis with formulation data could help predict durability and guide the development of safer paint systems.

3.13. Regulatory and health implications

The wide use of toxic metals, especially Pb, far above international limits, creates serious health risks. The findings here were part of the evidence that led to the 2024 revision of four Iranian standards (ISIRI 1700, 1554, 2225, 5475). These standards now require labeling of total lead content. The next steps are stronger enforcement and replacing hazardous pigments.

3.14. Lead content in decorative paints of neighboring countries: A comparative perspective

Comparative surveys and WHO–UNEP reports show that elevated lead levels in decorative paints are a regional issue:

- **Pakistan:** Market surveys have found paints with Pb >10,000 ppm, and WHO–UNEP notes that Pakistan has not yet adopted binding national limits.
- **India:** Adopted a binding 90 ppm limit in 2017. WHO–UNEP data confirm that India is among the 94 countries with enforceable laws.
- **Turkey:** As an EU candidate country, Turkey harmonized its regulations with EU directives, restricting Pb in paints to ≤90 ppm. WHO–UNEP lists Turkey among countries with binding controls.
- **Afghanistan:** WHO–UNEP reports no binding law; imported paints often exceed international limits.
- **Iraq:** Limited studies indicate that decorative paints frequently exceed 1,000 ppm Pb, with no binding national standards currently in place.
- **Iran (present study):** 79 % of tested samples exceeded 90 ppm, with maximum values reaching 13,206 ppm. The 2024 revision of four ISIRI standards introduced mandatory labeling, but enforceable numerical caps are still absent.

Comparative analysis

The findings suggest that Iran's situation is broadly similar to that of Pakistan and Iraq, where high lead levels remain common due to weak enforcement. In contrast, Turkey demonstrates the effectiveness of harmonization with EU standards, while India shows that regulatory adoption can reduce lead exposure over time. Iran's recent regulatory revisions represent an important step forward, but the absence of enforceable numerical limits continues to leave consumers at risk [31].

4. Conclusion

This study is the first to analyze the use of heavy metals in architectural paints in Iran. The analyses show that lead was the dominant contaminant in the paints, with concentrations ranging from 1.16 to 13,206 ppm, and 79 % of samples exceeded the World Health Organization (WHO) guideline value of 90 ppm. The yellow paint showed the highest lead level, consistent with the use of lead chromate pigments. The statistical analysis (ANOVA) showed that the paint color, brand, and their interaction ($p < 0.01$) are significant in the lead concentration of the paint. It was observed that metals such as PB-Cr, Pb-Sn, and As-Pb were correlated, suggesting that substituting unsafe pigments could reduce the simultaneous presence of multiple toxic metals. Notably, the results of this study informed the 2024 revision of four Iranian national standards (ISIRI 1700, 1554, 2225, and 5475), which now include labeling of lead content in decorative paints, representing an important regulatory step; however, the numerical limits remain lacking. By adopting a binding 90 ppm limit, as recommended by the WHO, national policies could be further aligned with international ones to enhance public health protection. Based on the finding that 79 % of samples exceed 90 ppm and that compliant white paints are already commercially available from multiple brands, we recommend adopting a mandatory 90 ppm lead limit for all architectural paints marketed in Iran. Our data indicate that this standard is both necessary, given the extreme concentrations observed, and achievable, as demonstrated by existing low-lead formulations.

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Declaration of generative AI and AI-assisted technologies in the writing process:

During the preparation of this work, the author(s) used Copilot to draw a graphical abstract, perform statistical analysis, summarize, and improve writing and readability in an academic style. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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