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A BASELINE STUDY ON MULTI-ELEMENT COMPOSITION AND HEALTH RISK ASSESSMENT OF WATER-BASED ARCHITECTURAL PAINTS IN BANGLADESH

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ABSTRACT

Architectural paints are used extensively across Bangladesh, yet limited data exist on their chemical composition or potential environmental and health impacts. This study quantified the elemental profiles of ten commercially available water-based wall paints using microwave-assisted acid digestion followed by Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES). Sixteen elements were measured, with emphasis on priority toxic metals including Pb, Cd, Cr, Ni, and Ba. The compositions were dominated by matrix elements commonly found in pigment and filler formulations, particularly calcium (average 157 ppm), aluminum (2.58 ppm), and titanium (1.31 ppm). All priority toxic metals were present at trace levels and were well below international limits for decorative paints. Maximum dry-weight concentrations were 0.21 mg/kg for Pb, 0.20 mg/kg for Cd, 0.86 mg/kg for Cr, 0.10 mg/kg for Ni, and 0.05 mg/kg for Ba, corresponding to <2% of BSTI, EU REACH, EN 71-3, and ASTM F963 thresholds. Cumulative health risk assessment using the Hazard Index (HI) approach indicated negligible non-cancer health risks (HI < 1) with Margins of Safety (MOS) ranging from 70× to 18,672× relative to applicable regulatory limits. While heavy metal concentrations in individual paints remain low, the large-scale generation of paint waste during construction and renovation, combined with poor disposal practices in Bangladesh, presents a significant cumulative environmental risk through soil and water contamination. This study provides the first comprehensive elemental baseline for water-based paints in Bangladesh and offers evidence to support strengthened regulatory oversight, guides industry quality assurance, and supports the development of sustainable paint disposal frameworks that protect environmental and public health.

Keywords: *Architectural Paints, ICP-OES, Heavy Metals, Hazard Index, Risk Assessment.*

1 INTRODUCTION

Architectural paints are a fundamental component of modern construction and interior design worldwide, serving as protective barriers and decorative finishes across residential, commercial, and industrial structures. Their formulations typically consist of pigments, polymer binders, solvents, fillers, plasticizers, and biocides, many of which are identified as potential sources of environmental contamination and human exposure to hazardous substances (Fan et al., 2024). Recent studies show that paints can release toxic heavy metals, volatile organic compounds (VOCs), microplastics, and antimicrobial additives throughout their life cycle, from production and application to weathering, renovation, and disposal (Forero-López et al., 2024; O'Connor et al., 2018).

Heavy metals remain a central concern in paint safety, with lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni), cobalt (Co), zinc (Zn), and arsenic (As) recognized as key chemical hazards because of their carcinogenic, neurotoxic, and ecotoxic effects (Akindele & Osibanjo, 2024; Megertu & Bayissa, 2020). Although many countries have introduced strict regulatory limits, lead-based paints are still widely detected in low and middle income regions. Surveys conducted across Asia, Africa, and South America reported that Pb concentrations exceeded 10,000 ppm, which is far above the 90 ppm benchmark adopted by at least 43% of all countries. (O'Connor et al., 2018; IISD, 2022). Research has revealed that 66% of new paint samples from China, India, and Malaysia contained lead concentrations above 5,000 ppm, with some exceeding 10% lead by weight. (Clark et al., 2006) Numerous studies indicate that Pb is frequently the most hazardous metal in decorative paints, with elevated levels in bright colours such as yellow, orange, and red, while Cd and Cr pigments also persist in various paints in the market. (Ali et al., 2025; Khan et al., 2021; Rebelo et al., 2015) Paint flakes and dust from aging, abrasion, renovation, and weathering represent significant exposure pathways through hand-to-mouth ingestion, inhalation of particulates, and leaching into the environment. (Akindele & Joseph, 2024). These patterns collectively illustrate why heavy metals remain a critical focus of paint-related risk assessments. Analytical methods such as ICP-MS, AAS, AFS, XRF, and XAS are used to quantify these metals, supporting the need for strict monitoring and regulation to reduce exposure. (He et al., 2024)

Beyond metals, paints have recently been identified as one of the largest contributors to global microplastic pollution. Weathered paint fragments release approximately 7.4 million metric tons annually, more than most other documented microplastic sources (Diana et al., 2025). These particles can transport embedded metals, plasticizers, and biocides into aquatic and terrestrial systems, amplifying their environmental persistence and toxicity. (Gaylarde et al., 2021; Müller et al., 2022) Volatile Organic Compounds (VOCs) function as solvents in paint but release emissions into indoor and outdoor environments that pose significant health and environmental risks. (Deveci et al., 2025; Jodeh et al., 2022; Liu et al., 2022; Wang et al., 2017) Life cycle assessments show that raw material production is the main environmental burden of paints, while incorporating waste paint and recycled packaging can reduce impacts up to 48%. (Paiano et al., 2021)

In Bangladesh, where waste management infrastructure remains underdeveloped in peri-urban and rural areas, improper disposal practices are commonplace. (Mihai & Taherzadeh, 2017) Paint residues are frequently discarded into open drains, water bodies, or landfills without adequate treatment, allowing toxic elements to leach into soil and aquatic systems. (Jolly et al., 2012; Siddiqua et al., 2022) Although the Bangladesh Standards and Testing Institution (BSTI) legally adopted a 90 ppm Pb limit in 2018, earlier investigations reported enamel paints containing Pb up to 114,010 ppm, more than 1,200 times the permissible level (Lokman Hossain et al., 2013.) Recent assessments indicate that the percentage of lead levels below 90 ppm increased from 23% in 2015 to 68–69% in 2021, showing significant progress in reformulation by manufacturers, yet solvent-based enamel paints sold in open markets still frequently exceed regulatory limits. (ESDO,2015; IPEN, 2021). At the same time, industrial discharges from paint factories have been linked with higher concentrations of Fe, Zn, Mn, Sr, and other metals in surrounding waters and agricultural soils, indicating wider environmental impacts (Gondal & Hussain, 2007; Sarker et al., 2022). Unlike many global markets, Bangladesh currently lacks binding regulations for VOCs, microplastics, biocides, or several other hazardous elements commonly found in paints.

Despite growing attention to paint-related contaminants, significant research gaps remain. Most local studies have focused exclusively on lead in solvent-based enamel paints, providing limited insights into other existing heavy metals. Very little is known about the elemental composition of water-based acrylic paints, even though these products are now widely used in household and commercial structures. Moreover, no comprehensive studies in Bangladesh have documented the environmental transport of paint-derived metals or provided systematic assessments of paint microplastics and VOC release into air, water, and soil. The absence of standardized analytical protocols further limits cross-study comparison and policy development within the country.

In response to these gaps, this study provides a comprehensive elemental characterization of commercially available wall paints in Bangladesh using ICP–OES, quantifying 16 elements, including major components (Ca, Al, Ti) and priority toxic metals (Pb, Cd, Cr, Ni, Ba). This work offers the first multi-element baseline for water-based paints in the country, with results evaluated against international regulatory standards (BSTI, EU REACH, ASTM F963, EN 71-3) to assess compliance and potential risks. This study addresses three key questions: (i) What concentrations of major and toxic metals are present in widely used decorative paints in Bangladesh? (ii) Do detected metal concentrations comply with international regulatory standards? (iii) What baseline data can inform future environmental and health risk assessment from these paints?

2 METHODOLOGY

2.1 The Sample Collection and Characterization

Ten water-based acrylic emulsion paint samples representing different colors and formulations were purchased from retail outlets in Khulna. The sampling strategy targeted five commercially recognized brands, including Berger Paints, Asian Paints, Nippon Paints, Olympic Paints, and Dunlop Paints, collectively representing approximately 65–70% of the regional paint market share for residential and commercial purposes. Samples were stored in zip-lock bags and sealed plastic containers at room temperature (20–25 °C) until analysis, as shown in Figure 1.

Figure 1 : Wall paint samples from ten renowned brands

2.2 Sample Preparation and Microwave Acid Digestion

Paint samples were digested using a PerkinElmer Titan MPS microwave digestion system. In each 75 mL high-pressure TFM vessel, 0.300g paint was combined with 8.0 mL HNO_3 (70%) and 2.0 mL H_2O_2 (30%), gently mixed with a glass rod, and allowed to pre-digest for approximately 10 minutes before vessel closure. The microwave digestion program consisted of three temperature ramps: 160 °C (5 min ramp, 10 min hold) at ≤30 bar, 190 °C (3 min ramp, 30 min hold) at ≤30 bar, and a cool-down phase at 50 °C (1 min ramp, 15 min hold). After cooling to room temperature, vessels were carefully opened in an open space. After digestion, samples were filtered through 0.45 µm PVDF membranes and diluted to 50 mL with ultrapure water, as shown in Figure 2, and the final diluted solutions prepared for ICP-OES analysis are displayed in Figure 3. (PerkinElmer Titan MPS Applications Notebook)

Figure 2: Filtration of digested paint samples

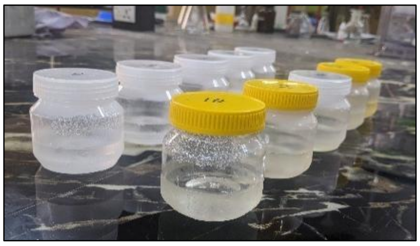

Figure 3: Diluted sample solutions

2.3 Heavy Metal Analysis by ICP-OES

2.3.2 Instrumentation and Analytical Method

Elemental determinations were performed using a Teledyne Leeman Labs Prodigy7 ICP-OES operated in accordance with U.S. EPA Method 6010D (U.S. EPA, 2018) and ASTM E1613-12. Samples were introduced via pneumatic nebulisation into an argon plasma (~10,000 K). Plasma gas flow (15–18 L/min), nebuliser gas flow (0.6–1.0 L/min), observation mode, and plasma power (1.2–1.3 kW) were optimised to maximise sensitivity and minimise spectral interference. A total of 16 elements were quantified, including priority toxic metals (Pb-208, Cd-111, Cr-52, Ni-60, Ba-137) and secondary elements (Al-27, Ca-43, Ti-49, Fe-57, Cu-63, Zn-64, Mg-26, Co-59, Mn-55, Bi-209, Mo-95). The analytical wavelengths were selected for their sensitivity and to avoid spectral overlap, following the guidelines in EPA 6010D Section 3.4. The overall workflow is illustrated in Figure 4.

2.3.3 Quality Assurance and Quality Control (QA/QC)

All QA/QC procedures followed U.S. EPA Method 6010D (SW-846, Rev. 5, 2018) and ASTM E1613-12 specifications. Table 1 summarises all QC parameters, acceptance criteria, and regulatory references.

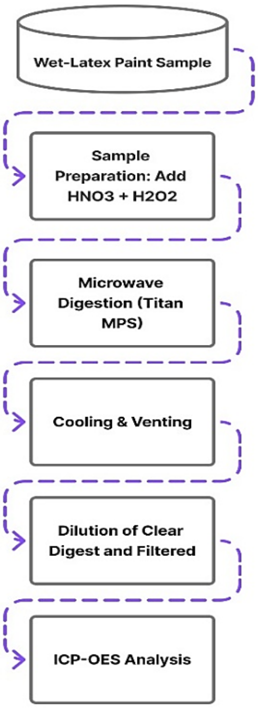

Figure 4: Flowchart of the digestion method

Table 1: QA/QC Summary Parameters

QC Parameter	Specification	Acceptance Criteria	Reference
Procedural Blanks	1 per digestion batch	< MDL	EPA 6010D Section 9.5
Calibration Verification (ICV/CCV)	Every 10 samples + start/end	90–110% recovery	EPA 6010D Section 9.4
Sample Replicates	n = 3 per sample	RSD < 10%	ASTM E1613
Matrix Spike Recovery	n = 2 samples	75–125%	EPA 6010D Section 9.6
Method Detection Limit	3× SD of blanks	Element-specific	40 CFR 136 App. B
Method Quantitation Limit	10× SD of blanks	Element-specific	EPA 6010D Section 9.2

Procedural blanks (8 mL HNO_3 70% + 4 mL H_2O_2 30%) were digested alongside samples in each batch to assess contamination from reagents and preparation procedures. Blank responses remained below the method detection limit (MDL = 3× SD of procedural blanks) for all 16 elements, validating the purity of reagents and digestion vessels. Sample replicates (n = 3) were analysed to establish measurement precision, with all results meeting the acceptance criterion of relative standard deviation (RSD) ≤10%. Mean RSD across all elements ranged from 2.8–8.4%, well below the acceptance threshold.

Matrix spike (MS) analyses (n = 2) were performed to assess matrix interference. Known concentrations of Pb, Cd, and Cr standards were added to pre-analysed digests, and percent recovery was calculated using Eq 1:

$$Recovery\ (\%) = \frac{C_{spiked\ sample} - C_{unspiked\ sample}}{C_{spike\ added}} \times 100 \qquad (1)$$

Where:

- C_{spiked} = Concentration measured after spiking (ppm)
- C_{unspiked} = Original concentration before spiking (ppm)
- $C_{\text{spike added}}$ = Known amount of standard added (ppm

Recoveries fell within the method-acceptable range of 75–125%. Calibration verification standards (ICV/CCV) were analysed every 10 samples and maintained 90–110% recovery, ensuring instrument stability. All reported concentrations exceeded the method quantitation limit (MQL). Certified reference materials (CRMs) specific to decorative paints were unavailable. However, spectral interferences were minimized through careful wavelength selection and background correction. Instrument drift remained within ±10%, and samples were analyzed in randomized order to reduce batch-related effects.

2.3.4 Wet vs. Dry Weight

Samples were analyzed in wet and fresh form, reflecting typical water-based architectural paint, which contains approximately 50–60% water and volatiles (ASTM D4017-02, 2015; Resene Paints Ltd., 2005; Carbit Paint Company). This approach differs from standard dried film methods such as ASTM E1645 and ISO 6503:1984. Thus, all measured concentrations are reported on a wet-weight basis. For comparison with regulatory limits expressed on a dry-weight basis, Eq 2 was applied:

$$C_{dry} = \frac{C_{wet}}{0.45} \approx 2.2 \times C_{wet} \tag{2}$$

Where:

- C_{dry} = Concentration on dry weight basis (ppm)
- C_{wet} = Concentration on wet weight basis, as measured (ppm)
- Solid Content Fraction = 0.45 (45% solids in latex paint; 55% water/volatiles)

This distinction is important because regulatory thresholds for metals in paints are defined for dried coatings. All compliance assessments in this study, including comparisons with international standards and calculation of Hazard Index (HI), were therefore conducted using dry-weight values derived from the 2.2× conversion factor.

2.3.5 Margin of Safety (MOS)

The Margin of Safety (MOS) was calculated as the ratio of the applicable regulatory limit to the maximum detected concentration on a dry weight basis, following standard risk assessment methodology (U.S. EPA, 1993; U.S. EPA, 2012). This relationship is expressed in Eq 3 :

$$MOS = \frac{RL}{C_{Max}} \tag{3}$$

Where:

- RL = Regulatory Limit (ppm)
- C_{Max} = Maximum Detected Concentration (dry weight)

An MOS ≥ 100 is generally considered protective for substances with threshold toxicity effects.

2.3.6 Hazard Index (HI) Analysis

The cumulative non-cancer health risk from multiple heavy metals was assessed using the Hazard Index (HI) approach, following U.S. EPA Risk Assessment Guidance for Superfund (RAGS),1989. The HI is calculated as the sum of individual hazard quotients (HQs), as shown in Eq 4:

$$HI = \sum_{i=1}^{n} HQ_i = \sum_{i=1}^{n} \frac{C_i}{RfC_i} \tag{4}$$

Where:

- HQ_i = Hazard Quotient for metal *i*
- C_i = Measured concentration of metal *i* (ppm, dry weight basis)
- L_i = Regulatory limit or reference concentration for metal *i* (ppm)
- RfC = Reference Concentration

An HI > 1 suggests that combined exposures may exceed acceptable non-cancer risk levels.

3 RESULTS AND DISCUSSION

3.1 Regulatory Framework and Analytical Approach

While many jurisdictions have adopted a total lead limit of 90 ppm for decorative paints, there are no globally harmonized concentration limits for most other heavy metals in architectural coatings. The European Union's REACH regulation specifies a total cadmium content limit of 0.01% (100 ppm) in most paints, with a 0.1% (1000 ppm) threshold for certain high-zinc formulations. However, no comparable numeric limits are established for chromium, nickel, and barium in architectural paints; therefore, ASTM F963 standard migration limits (60 ppm for Cr and Ni; 1000 ppm for Ba) were applied as conservative health-based benchmarks.

3.2 Elemental Profile of Wall Paint Samples

ICP-OES analysis of ten commercial wall paint samples (PS1-PS10) revealed a multi-element profile dominated by base pigments and extenders, with trace amounts of regulated heavy metals. Calcium and aluminum were the most abundant metals, consistent with the widespread use of calcium carbonate and aluminosilicate fillers in decorative coatings. Mean Ca was 157 ppm (range 4.86–416 ppm), and mean Al was 2.58 ppm (0.0198–6.47 ppm). Titanium, present mainly as TiO_2 white pigment, averaged 1.31 ppm (non-detect–3.35 ppm). The distribution of these major elements across all ten samples is shown in Figure 5. These concentrations align with expected ranges for water-based architectural paints, where $CaCO_3$ and TiO_2 represent primary pigment and extender components. (Karakaş et al., 2015)

In contrast, the levels of priority toxic metals, including Pb, Cd, Cr, Ni, and Ba, were consistently present at low concentrations (shown in Figure 6). Chromium (Cr) was the only regulated metal detected in all ten samples, whereas Ba was observed in only one sample and at a minimal level. Lead, cadmium, and nickel were likewise present at trace concentrations. (shown in Figure 8)

All ICP-OES measurements met the QA/QC acceptance criteria described in Section 2.3.3, confirming the accuracy and reliability of reported concentrations.

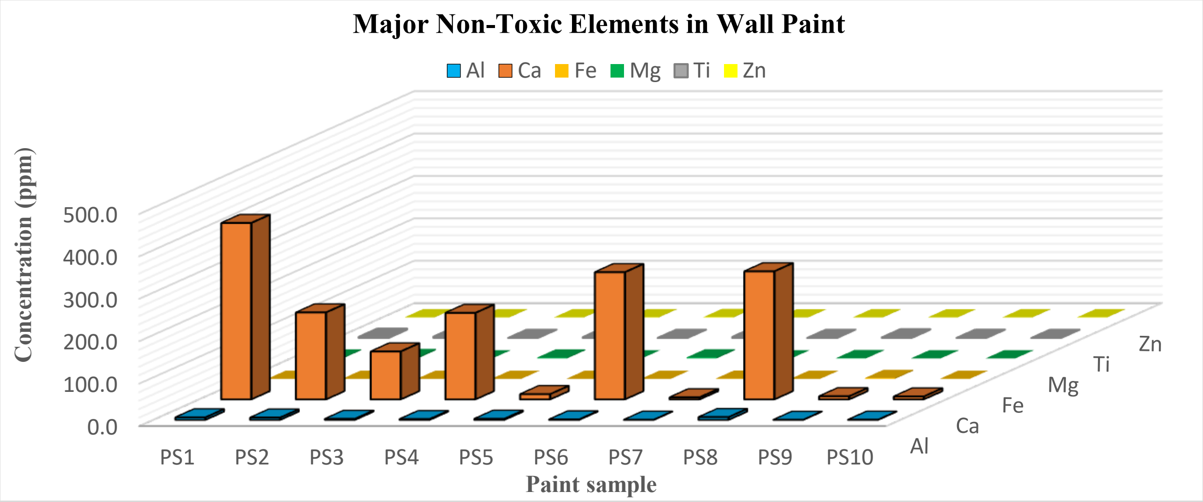

Figure 5: Distribution of major non-toxic elements (Ca, Al, Ti, Mg, Fe) in wall paint samples. All values are expressed on a wet weight basis (ppm)

3.3 Priority Toxic Metals: Concentrations and Regulatory Compliance

Lead (Pb) concentrations ranged from non-detect to 0.0961 ppm (wet basis), equivalent to 0.21 ppm dry weight, representing only 0.24% of the 90 ppm regulatory limit for decorative paints. Lead was detected sporadically across samples, with the mean Pb concentration (0.0256 ± 0.0306 ppm) confirming full compliance with BSTI and international standards and as shown in Figure 6.

Cadmium (Cd) was detected in six samples at trace levels, having a maximum of 0.0918 ppm (0.20 ppm dry), corresponding to 0.20% of the EU REACH 100 ppm limit. The mean concentration (0.0308 ± 0.0360 ppm) indicates that Cd-based pigments are no longer used, and detected Cd likely reflects raw-material impurities through Zn- or Bi-based pigments.

As shown in Figure 6, Chromium (Cr) was the only regulated metal detected in all samples, with concentrations of 0.0073–0.3868 ppm on a wet weight basis. The maximum dry-weight equivalent of 0.86 ppm represents 1.43% of the ASTM F963 limit for total Cr; slightly higher levels in PS4, PS6, and PS8 are consistent with Cr_2O_3-based green pigments.

Nickel was detected at trace levels at a maximum concentration of 0.0432 ppm, equivalent to 0.10 ppm on dry weight basis, representing 0.16% of the ASTM F963 limit with a 625-fold margin of safety. Barium appeared in only one sample (PS10) at a trace level of 0.0241 ppm (wet), equivalent to 0.05 ppm (dry), representing 0.005% of the 1000 ppm ASTM F963 limit. Both Ni and Ba levels are shown in Figure 6, highlighting their negligible regulatory concern. Detection frequencies for all regulated metals are presented in section 3.5.

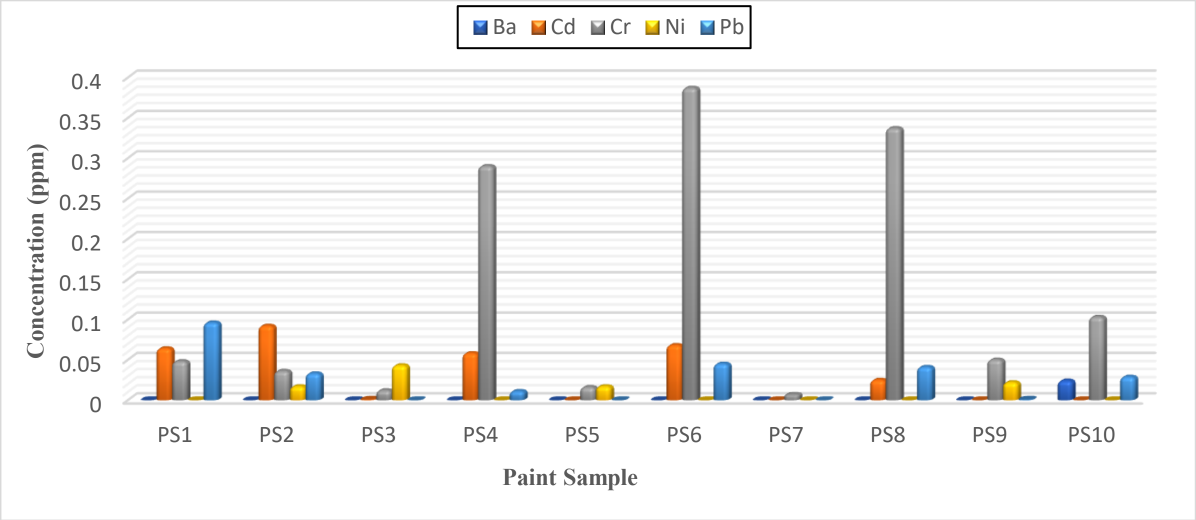

Figure 6: Concentrations of priority heavy metals (Pb, Cd, Cr, Ni, Ba) in wall paint samples. All values are expressed on a wet weight basis (ppm)

A summary of regulatory thresholds, maximum detected concentrations (dry basis), compliance assessment, and calculated MOS values (Eq. 3) is presented in Table 2. All detected metals remained far below their respective limits, with MOS values ranging from 70× (Cr) to over 18,000× (Ba), demonstrating substantial safety margins across all samples.

Table 2 : Regulatory Compliance and MOS

Element	**Limit (ppm)**	**Max Detected (Dry)**	**% of Limit**	**MOS**	**Applicable Standard**	**Compliance**
Pb	90	0.21	0.24%	421×	Decorative Paint Standard	✓
Cd	100	0.20	0.20%	490×	EU REACH Regulation	✓
Cr	60	0.86	1.43%	70×	ASTM F963/EN 71-3*	✓
Ni	60	0.10	0.16%	625×	ASTM F963*	✓
Ba	1000	0.05	0.005%	18,672×	ASTM F963/EN 71-3*	✓

*ASTM F963/EN 71-3 Toy standard migration limits are used as conservative health-based benchmarks where no specific architectural paint limits exist.

3.4 Cumulative Risk Assessment: Hazard Index Analysis

To characterize the combined non-cancer health risk from multiple metals, the cumulative Hazard Index (HI) was calculated using Eq. 4. For each sample, individual Hazard Quotients were calculated as HQ = C/RL, where C is the measured concentration (dry weight, ppm) and RL is the applicable regulatory limit. Because all metals in this study were evaluated against fixed regulatory thresholds (Section 3.3), the HI can be expressed clearly as:

$$HI = \frac{C_{\text{Pb}}}{90} + \frac{C_{\text{Cd}}}{100} + \frac{C_{\text{Cr}}}{60} + \frac{C_{\text{Ni}}}{60} + \frac{C_{\text{Ba}}}{1000} \tag{4a}$$

Within the U.S. EPA non-cancer risk framework, an HI < 1 indicates negligible risk, while HI > 1 may signal potential for adverse health effects. All ten samples exhibited HI values far below 1.0. The maximum HI was 0.0169 (PS6), corresponding to only 1.7% of the risk threshold, and the distribution of HI across samples is illustrated in Figure 7. The mean HI was 0.0065 ± 0.0048, with individual values ranging from 0.00027 (PS7) to 0.0169 (PS6).

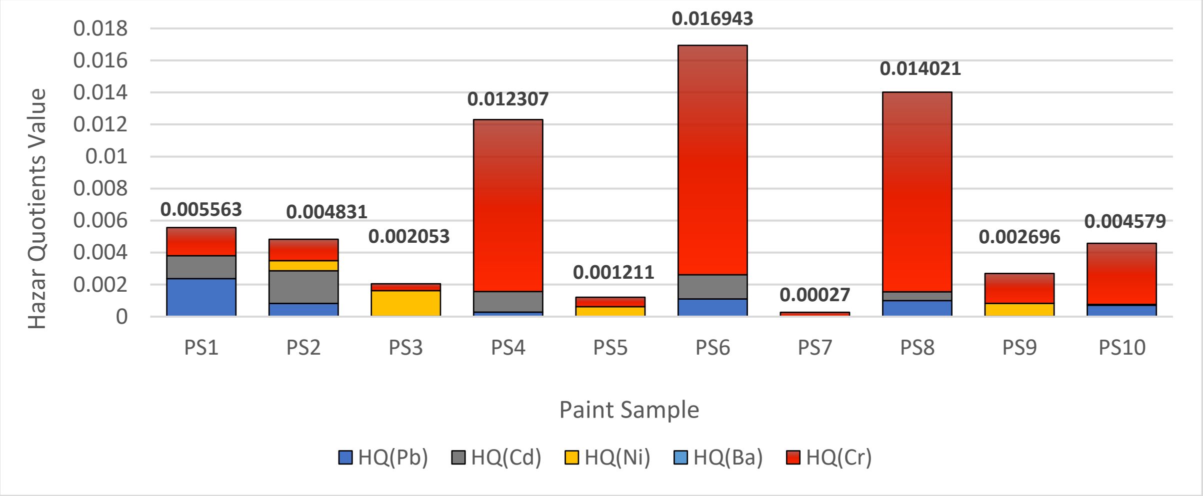

Figure 7: Cumulative Hazard Index (HI) showing individual metal contributions for each paint

Table 3 summarises the HI values, dominant contributing metals, and the percentage contribution of each metal for every collected sample.

Table 3: Cumulative Hazard Index (HI) by sample

Sample	HI (Total)	Risk Level	Dominant Metal	Pb Contribution	Cr Contribution	Cd Contribution
PS6	0.0169	Low	Cr	1.2%	84.8%	8.9%
PS8	0.0140	Low	Cr	7.1%	88.9%	3.9%
PS4	0.0123	Low	Cr	2.3%	87.4%	10.4%
PS1	0.0056	Low	Pb	42.6%	31.6%	25.7%
PS9	0.0027	Low	Cr	0.8%	69.3%	0.0%
PS2	0.0048	Low	Cd	17.2%	27.9%	42.5%
PS10	0.0046	Low	Cr	15.5%	83.0%	0.0%
PS3	0.0021	Low	Ni	0.0%	20.5%	1.1%
PS5	0.0012	Low	Cr	0.0%	49.1%	0.0%
PS7	0.0003	Low	Cr	0.0%	90.0%	0.0%

As shown in Table 3, chromium was the predominant element influencing the HI in most cases, contributing 70–89% to the total. Lead and cadmium contributed less significantly, typically 5–30% and 2–15%, respectively, while nickel and barium contributions were negligible. This distribution highlights that, under the ASTM F963 toy standard framework, chromium becomes the primary metal for paint risk characterization. However, the absolute contributions remain negligible in all instances. Overall, the absolute HI contributions remain negligible in all samples, confirming that Bangladeshi water-based paints pose minimal non-cancer health risk from heavy metal exposure.

3.5 Detection Frequency of Heavy Metals

Detection frequency analysis distinguishes components that were consistently present from sporadic impurities. Among the five regulated metals, detection frequencies varied noticeably: chromium (Cr) appeared in all ten samples (100%), lead (Pb) in seven samples (70%), cadmium (Cd) in six samples (60%), nickel (Ni) in four samples (40%), and barium (Ba) in only one sample (10%). These results are shown in Figure 8. All frequencies are based on replicate measurements with RSD ≤ 10%, as described in Section 2.3.3.

Chromium's universal presence (100% detection frequency) confirms its intentional use as a common pigment or additive in water-based paints in Bangladesh, whereas Ba is clearly not an intended component in most of the tested products. Lead and cadmium, although detected in the majority of samples (70% and 60%, respectively), occur only at ultra-trace levels, suggesting minimal use in water-based acrylic paints. Nickel's sporadic detection at trace concentrations implies a negligible or absent role in modern paint in Bangladesh.

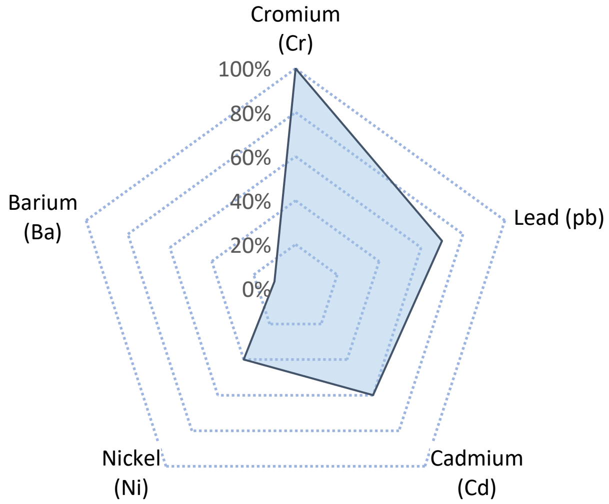

Figure 8: Detection frequency of priority heavy metals in ten wall paint samples

4 CONCLUSIONS

This study provides a comprehensive elemental assessment of water-based architectural paints available in Bangladesh, with emphasis on priority toxic metals. Across ten products from major commercial brands, concentrations of Pb, Cd, Cr, Ni, and Ba were low and remained below 1.43% of relevant international limits after conversion to a dry-weight basis. Lead, which has been a long-standing concern in decorative paints, was found only at trace levels. (<0.24% of the permissible limit). Chromium was found in all samples, but the concentration levels are not a significant health concern. Margin-of-safety calculations were high for all metals, and the cumulative Hazard Index values were well below 1, confirming negligible non-cancer health risks from heavy metal exposure through these paints.

The findings suggest that water-based paints currently sold by leading brands comply with established heavy-metal standards. However, the lack of national regulations for VOCs, microplastics, biocides, and other emerging contaminants indicates that existing controls do not fully address the broader chemical profile of architectural paints. This assessment is limited to ten water-based samples from urban retailers in Khulna and focuses exclusively on heavy metal characterization. A more complete understanding will require studies that include solvent-based paints, expanded elemental and organic chemical analysis, and assessment of environmental pathways associated with paint use, weathering, and disposal. Future research should also quantify VOC emissions during and after application and evaluate the release of paint-derived microplastics into environmental compartments.

Overall, this study offers baseline data for national monitoring efforts and highlights the need for more comprehensive regulatory frameworks for architectural coatings in Bangladesh.

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DECLARATION OF USE OF AI

Artificial intelligence tools (specifically Perplexity AI) were used to support grammar refinement, clarity improvements, and language editing during manuscript preparation. No AI tool contributed to the generation of scientific ideas, data collection, analytical methodology, statistical analysis, results interpretation, or conclusions. All AI-assisted text was reviewed and validated by the authors.

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