Portable X-ray fluorescence spectrometry: a cost-effective method for analysing trace metals in deposited dust†

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For projects requiring extensive environmental sampling and rapid decision-making to identify trace metal contamination using dust wipes, the cost and time required for wet chemistry analysis can be prohibitive. Under such circumstances there is a need for a suitable screening method that is cost-effective, efficient, and portable. To address this need, this study investigated the utility of portable X-ray fluorescence (pXRF) for the analysis of trace metals in dust wipes. Here, 316 dust wipe samples from three different geographical settings co-located with mining and smelting operations were investigated for their trace metal loadings (µg m⁻²) of arsenic (As), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) using pXRF. Results collected using pXRF were compared against inductively coupled plasma mass spectrometry (ICP-MS) concentrations using matched dust wipes (n = 87) to assess reproducibility. A subset of dust wipes (n = 4) were subject to different pXRF analytical scenarios (ranging from 1 to 12 pXRF measurements) using a standardised test duration of 30 seconds to identify the most efficient number of tests for analytical precision. Conducting four pXRF tests on a single wipe (total exposure time of 120 seconds) returned comparable results to ICP-MS and was adopted for analysis of all samples. Results from dust wipes analysed with both ICP-MS and pXRF (n = 87) showed moderate to strong Spearman Rho correlations (rs = 0.489–0.956, p < 0.01) and linear regression coefficients of variation demonstrated good agreement between methods (R² = 0.432–0.989, p < 0.05). Linear regression equations were used to correct pXRF data to the ICP-MS dust wipe data for samples analysed by both approaches, and applied to pXRF data that were not subject to ICP-MS analysis (n = 229). Application of the correction formula resulted in a substantial improvement of pXRF’s accuracy and precision, confirming its effectiveness for assessing trace metals in dust wipes.

1. Introduction

Industrial activities generate and disperse contaminants through atmospheric emissions and dust depositions. Mining, smelting, and processing industries have been shown to increase trace metal or metalloid contaminants (hereafter referred to as trace metals or simply metals) in the surrounding environment.⁵,⁶ The presence of toxic trace metal contaminants can pose a significant health risk to impacted individuals and communities.⁴ For instance, chronic exposure to low concentrations of arsenic (As) can cause various health effects, including respiratory and cardiovascular diseases;⁷ chronic exposure to hexavalent chromium (CrVI) is associated with lung cancer and adverse respiratory effects;⁸ and lead (Pb) exposure can cause lifelong neurological and developmental detrimental outcomes.⁦⁷

Consequently, monitoring and assessment of potential toxic trace metal mobilisation and deposition in human environments is crucial when assessing health risks from exposure, especially in areas associated with mining and smelting.⁸ Monitoring methods vary depending on the target exposure route to be analysed. For example, gravimetric (measuring natural particle deposition) and high-volume air sampling (drawing a known volume of air through a pre-weighed filter over a set time period) target the inhalable fraction of airborne particles. These methods rely on placing equipment in fixed locations and sampling a single location at a time, limiting the spatial representativeness of sample heterogeneity associated with airborne contaminants.⁸ Other dust sampling methods employed widely in exposure studies include sweeping or vacuuming settled dust, which may collect only a narrow spectrum of particles, particularly coarse particles.⁹,¹⁰

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Dust wipe sampling is an efficient alternative method for manually collecting surface-settled dust particles from a targeted area. Compared to air sampling or settled dust collection, dust wipe sampling offers several advantages, including greater representativeness from multiple sampled surfaces in a single location, and easy and cost-effective sample collection. Perhaps most importantly, a dust wipe collects a broad spectrum of particles representing ingestion, inhalation, and dermal contact exposure pathways more closely. Dust wipe sampling has been used to assess potential skin absorption and ingestion (particularly with respect to children) by contact exposure and uptake from a contaminated surface, particularly for Pb contamination assessment.

While dust wipe sampling is often used to assess Pb and asbestosiform contaminants in indoor environments, its application for assessing other trace metals and outdoor environments is less common. Analysis of dust wipe samples is traditionally carried out using ex situ wet-chemistry methods such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) which is considered the ‘gold standard’. However, the financial cost and time-consuming nature of this technique limits how many samples can feasibly be assessed in a study, and presents potentially critical delays for decision-making and intervention measures. Portable X-ray fluorescence (pXRF) provides rapid, inexpensive, real-time data on contaminant levels, enhancing risk management in large-scale projects.

Advances in pXRF technology have greatly improved quantification, resulting in reliable geochemical measurements that are equal to or better than those obtained through traditional methods. Analysis of dust wipes using pXRF can occur near-in situ (short delay to accommodate wipe drying) at field sites, or ex situ if wipes are stored appropriately. However, research on pXRF application for the analysis of dust wipes is limited, with most studies focusing solely on Pb.

This article compares the results from dust wipes collected in three sampling campaigns and analysed using both pXRF and ICP-MS. Sampling campaigns were undertaken in the mining and smelting towns of Nouméa and Thio in New Caledonia, and Tsumeb in Namibia. The data were examined to assess the potential viability of using pXRF to expedite dust wipe analyses at a reduced financial and time cost.

2. Methods

2.1. Study locations

This study investigates dust wipe samples from three sampling campaigns: (1) Tsumeb, Namibia; (2) Nouméa, New Caledonia; and (3) Thio, New Caledonia. These localities all have a rich history of mining and smelting.

2.1.1. Tsumeb case study. Tsumeb, located in northern Namibia and southwestern Africa, is known for its mineral deposits hosting copper (Cu), lead (Pb) and zinc (Zn), and has been mined for over a century. The region is home to a metal smelting and refining industry that specialises in processing complex Cu and Pb concentrates. It is one of a limited number of global facilities capable of processing ores high in As, producing blister Cu bars and As trioxide. Research has indicated the presence of elevated concentrations of smelter-related trace elements in the surrounding environment, with potential impacts on ecological and human health in residential areas near to the facility. Arsenic, Cu, Pb, and Zn in deposited dust were assessed in this case study.

2.1.2. Nouméa case study. New Caledonia is a French territory in the South-West Pacific Ocean with a strong economic reliance on nickel (Ni) mining and smelting. Mining was first documented in 1873, and New Caledonia is the world’s fifth largest producer of Ni. The Doniambo smelter, located in the capital city of Nouméa, was established in 1910 and remains one of the largest Ni smelters in the world. Despite its economic importance to New Caledonia, the Doniambo smelter has faced scrutiny due to its impact on the environment, biota and potential effects on human health, particularly given its proximity to residential areas. Hence, the metals of focus in this case study are smelting-derived contaminants of chromium (Cr), iron (Fe) and Ni, geogenic manganese (Mn), along with anthropogenic sources of Pb and Zn.

2.1.3. Thio case study. Thio, New Caledonia, is home to several Ni mines, including the Plateau de Thio mine, owned by Société Le Nickel, one of the largest Ni mining companies in the world. With over a century of opencast mining, Thio has produced approximately 20 million tonnes of Ni, managing over 100 million tonnes of waste material through these mining operations. In addition to natural enrichment and erosion of the mafic laterite rocks, a century of Ni ore extraction and processing has further elevated the metal content in the environment, raising health concerns among the local population.

Metals assessed from this case study location include the regionally and mining enriched Cr, Fe, Mn, Ni, along with anthropogenic sources of Pb and Zn.

2.2. Sample collection

In all cases, the aim was to collect surface dust samples using Ghost Wipes from a 30 × 30 cm surface (90 cm² area), where the appropriate surface area was available using standard procedures. Each specific wipe area was recorded, allowing trace metal values (µg) per wipe to be converted to a standard mass/area (µg m⁻²).

The collected wipes were placed in labelled resealable zip-lock plastic bags, air-dried in an indoor laboratory environment for 48 hours to remove residual moisture, and then mounted in Lighthouse® 39 mm mylar coin pouches for pXRF analysis (Fig. 1). Air-drying was chosen over oven-drying to avoid potential damage (e.g., shrinking, melting, or becoming brittle) to the wipes so as not to impact subsequent analysis.

A total of 316 samples were collected across the three case study locations. The samples comprised: 80 outdoor collected dust wipe samples from Tsumeb in July 2018; 111 outdoor collected dust wipes from Nouméa in July 2019; and 125 dust wipes (comprising 23 indoor dust samples and 102 outdoor samples) from Thio in July 2022.

Samples were collected across each locality to understand the extent of contamination. ESI Table S6 identifies the
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Vanta pXRF equipped with 4 W rhodium X-ray tube and per square meter (Fe, Mn, Ni, Pb and Zn were converted to loadings in micrograms checks, were followed to ensure optimal instrument function. MS sample measurements. Using the linear regression equation derived from matched ICP-MS analysis as explained in Sections 2.3 and 2.6.

2.3. pXRF analysis

Dust wipe samples were analysed ex situ in quadrants (see Section 2.6 for more information). Each quadrant was exposed to three 10 seconds pXRF beams, providing a test time of 30 seconds per quadrant (120 seconds per dust wipe). A silicate blank (SiO₂) was placed over the back of the wipe to minimise X-ray backscatter.

Operational procedures, including frequent calibration checks, were followed to ensure optimal instrument function.² Nineteen samples were selected for instrumental analysis, and four blank wipes were undertaken to ensure data quality. And determine trace metal levels present in the wipes before field use (ESI Table S1†).

Dust wipes from Tsumeb (first campaign, n = 80) were analysed for As, Cu, Pb and Zn using a 50 kV Olympus Delta Premium pXRF equipped with 4 W X-ray rhodium tube and a silicon drift detector operating in dust wipe mode (µg ft⁻²). Analyses were subsequently converted to micrograms per square metre (µg m⁻²).

The manufacturer limits of detection (LOD) for trace metals expressed as mg kg⁻¹ using the Delta pXRFs were: As (2–4 mg kg⁻¹), Cu (5–7 mg kg⁻¹), Pb (3–5 mg kg⁻¹) and Zn (5–7 mg kg⁻¹). Samples from Nouméa (second campaign, n = 111) and Thio (third campaign, n = 125) were analysed using a 50 kV Olympus Vanta pXRF equipped with 4 W rhodium X-ray tube and a silicon drift detector in soil mode (mg kg⁻¹). Analyses for Cr, Fe, Mn, Ni, Pb and Zn were converted to loadings in micrograms per square meter (µg m⁻²). This conversion first considered the wiped area (m²), and then the pXRF data were transformed using the linear regression equation derived from matched ICP-MS sample measurements.²⁴,²⁹

The manufacturer LOD for trace metals using the Vanta instrument were Cr (5 mg kg⁻¹), Fe (5 mg kg⁻¹), Mn (2 mg kg⁻¹), Ni (2 mg kg⁻¹), Pb (1 mg kg⁻¹) and Zn (1 mg kg⁻¹).

2.4. ICP-MS analysis

A total of 87 dust samples (Tsumeb = 25, Nouméa = 35, and Thio = 27) were submitted to the National Measurement Institute (NMI) in North Ryde, Sydney, Australia, for ICP-MS trace metal analysis. To ensure samples sent for ICP-MS analysis were suitably representative of the dataset, an analysis of trace metal distributions was carried out comparing trace metal loadings in all dust wipes analysed by pXRF to the subset of samples analysed both pXRF and ICP-MS. This revealed no significant differences in trace metal distribution between the datasets (Tsumeb [19%, n = 10/53], Nouméa [31%, n = 34/109], and Thio [21%, n = 27/123]), supporting the validity of the selected subset of samples for ICP-MS analysis (ESI Fig. S1–S3†).

ICP-MS analysis was carried out using an Agilent 7900 Quadrupole ICP-MS following National Association Testing Authorities (NATA) accredited methods.⁷ Dust wipes were digested using a mixture of HNO₃ and concentrated HCl (3 mL), heated at 100 °C for 90 min. High-purity water was added (10 mL), with digestion continued for an additional 30 min. The resulting digest solutions were diluted with high-purity water to reach a total volume of 40 mL. Laboratory control samples (LCS) (n = 7) and matrix spikes (n = 7) were measured, with all analyses within an acceptable range of 80–120%. Blank wipes were analysed for quality control, including five ‘unopened’ wipes and one ‘laboratory’ wipe removed from the packet, folded as per the dust wipe method previously described, and then stored in a coin holder (ESI Table S2†).

The LODs obtained for the metals investigated in the Tsumeb case study were: As (<0.01 µg per (wipe) sample), Cu (<0.05 µg per sample), Pb (<0.05 µg per sample) and Zn (<0.1 µg per sample). The LODs for the Nouméa and Thio case studies were Cr (<0.1 µg per sample), Fe (<0.5 µg per sample), Mn (<0.05 µg per sample), Ni (<0.05 µg per sample), Pb (<0.05 µg per sample) and Zn (<0.1 µg per sample).

2.5. Data correction and statistical analysis

The relationship between pXRF and ICP-MS results of dust wipes measurement was established using linear regression plot analysis. Linear regressions were applied to pXRF measurements as ‘correctional equations’ after solving for ‘y’ in ‘y = mx’ where x was the concentration of the metal of interest measured by pXRF. ²⁶

The quality of data correction was evaluated using the coefficient of determination (R²) and a comparison between pre-correction and post-correction using % recovery. Recovery describes the relative pXRF concentration to ICP-MS concentration based on analysis of the same samples, expressed as percentage (cf. ref. 29 and 48):

\[
\text{Recovery} \% = \left( \frac{\text{pXRF}}{\text{ICP-MS}} \right) \times 100 \quad (1)
\]
Data quality was evaluated according to the coefficient of determination as follows: definitive level ($R^2$: 0.85–1; the datasets are statistically similar); quantitative screening level ($R^2$: 0.70–0.85; notable statistical similarity); qualitative screening level ($R^2 < 0.70$; datasets are statistically different and do not provide reliable concentration estimates).

Correctional equations were applied to the remaining pXRF data that did not undergo ICP-MS analysis (Tsumeb $n = 55$, Nouméa $n = 76$, Thio $n = 98$). These correctional equations were calculated and applied to each study area representatively, meaning they were fitted to the characteristics of each location and cannot be interchanged or extrapolated to other regions.

Since the data were not normally distributed, Spearman’s Rho correlation was used to investigate the relationship between pXRF and ICP-MS data of trace metals using Minitab 17.

2.6. Subset dust wipe analysis

An analysis of a subset of dust wipes (SDW; $n = 4$) from the Tsumeb case study was conducted to determine the minimum number of tests required to ensure precision and accuracy while balancing the demand for a shorter testing time. A 50 kV Olympus Vanta pXRF, fitted with a tungsten tube, was used for the SDW. Seven scenarios varying in the number of tests per wipe (ranging from 1 to 12 tests) were applied within 30 second timeframes per test, resulting in total test times ranging from 30 to 360 seconds per wipe (Fig. 2).

3. Results

3.1. Subset dust wipe analysis

The analysis of the SDW by pXRF ($n = 4$) from the Tsumeb case study showed that increasing the number of tests reduced analytical variation (ESI Table S3†). Analysing dust wipes using four test runs (30 seconds per run), hereafter referred to as quadrant analysis, showed the most consistency between tests with reasonable exposure testing time (120 seconds) compared to other scenarios (ESI Table S3†). Thus, the quadrant analysis approach was identified as the most optimal approach for producing quality results while minimising pXRF sample time. Quadrant analysis was taken as the benchmark pXRF concentration (i.e. representing ‘100%’ of the concentration) and compared against the results from the other test scenarios to observe the variations in trace metal values (Fig. 3). Compared to the quadrant analysis, the average concentration measured in dust wipes fluctuated from 93% to 107% depending on the analysed trace metal and test scenario (number of tests and exposure time) (Fig. 3). Therefore, some variability ($\pm 10\%$) is anticipated from the approach applied here.

3.2. Case studies pXRF vs. ICP-MS data

For each case study, the quality of data obtained through pXRF was compared to the results from ICP-MS via Spearman correlation analysis. Spearman correlation analysis was performed separately for each of the three case studies.

Tsumeb dust wipes revealed a moderate statistically significant correlation between pXRF and ICP-MS concentrations for As ($r_s = 0.652, p < 0.01$), Pb ($r_s = 0.674, p < 0.01$), and Zn ($r_s = 0.489, p < 0.05$). A strong significant relationship was identified for Cu ($r_s = 0.735, p < 0.01$).

Nouméa case study correlation analysis between pXRF and ICP-MS analysed dust wipes showed a strong, statistically significant correlation for all assessed trace metals: Cr ($r_s = 0.834, p < 0.01$), Fe ($r_s = 0.938, p < 0.01$), Mn ($r_s = 0.736, p < 0.01$), Ni ($r_s = 0.956, p < 0.01$), and Zn ($r_s = 0.756, p < 0.01$), but only a moderate correlation for Pb ($r_s = 0.694, p < 0.01$).
The dust wipes analysed from Thio showed strong correlations between concentrations for dust wipes analysed by pXRF and ICP-MS in the case of Fe ($r_s = 0.912$, $p < 0.01$), Ni ($r_s = 0.918$, $p < 0.01$), Cr ($r_s = 0.896$, $p < 0.01$), Mn ($r_s = 0.848$, $p < 0.01$) and Zn ($r_s = 0.938$, $p < 0.01$). A moderate correlation was found between pXRF and ICP-MS Pb concentrations in Thio’s wipes ($r_s = 0.647$, $p < 0.01$).

### 3.3. Data quality for corrected pXRF data

Linear regression analysis of dust wipes data that were subjected to both pXRF and ICP-MS analysis (Tsumeb = 25, Nouméa = 35 and Thio = 27) yielded variable coefficients for the different trace metals analysed. The three case study datasets were benchmarked against a categorical quality classification for data acquired on pXRF (Table 1).

Definitive data quality was found in Tsumeb for all trace metals analysed in dust wipes ($R^2 = 0.948–0.989$). For dust wipes from Nouméa, a definitive quality was obtained for Fe ($R^2 = 0.882$), Ni ($R^2 = 0.931$), and Pb ($R^2 = 0.851$), a quantitative quality was achieved for Mn ($R^2 = 0.823$) and Zn ($R^2 = 0.753$) analysis, and a qualitative quality for Cr data ($R^2 = 0.564$) (Table 1). Thio dust wipes showed a definitive quality for Fe ($R^2 = 0.949$), Ni ($R^2 = 0.896$), and Zn ($R^2 = 0.938$) quantitative for Cr ($R^2 = 0.808$), and Mn ($R^2 = 0.819$). Contrastingly, Pb from Thio showed a qualitative classification and the lowest quality detection of the trace metals investigated (Pb – $R^2 = 0.432$).

The coefficients of determination were predominantly high ($R^2 > 0.750$) across the three studied cases, with exceptions noted for Cr in the Nouméa case study ($n = 35$) and Pb in the Thio case study ($n = 27$), likely caused by low concentrations or patchy distribution of dust on the wipe leading to a significant difference between ICP-MS and pXRF results. This arises because ICP-MS involves digestion and analysis of the whole wipe, whereas the pXRF approach of using quadrants analysis, will only measure a fraction of the total deposited dust. The Tsumeb case study ($n = 25$) yielded the most favourable outcomes for recovery ($x = 75$, range: 21–148%), generally reflecting a good concordance between pXRF and ICP-MS results. Nouméa dust wipes ($n = 35$)
showed generally favourable results in recovery ($x = 174$, range: 136–265%), with most disparity between pXRF and ICP-MS results for Mn (Table 1). Thio dust wipes showed relatively good results for recovery ($x = 303$, range: 105–534%), except for the highest variability in recovery (534%) for Cr (Table 1).

Equations obtained by the linear regression plot analysis of matching pXRF and ICP-MS dust wipe concentrations data provided a ‘correction’ factor for adjusting pXRF data. These equations aimed to enhance the quality of pXRF analyses, aligning them more closely with those provided by ICP-MS (Fig. 4; ESI Fig. S4–S6†).

Notably, applying a correction to pXRF data using a small subset of samples analysed with ICP-MS resulted in an improvement of results (Fig. 4), evident in the improvement of recovery values from 75 to 100% for Tsumeb, 174 to 92% for Nouméa and from 303 to 110% for Thio (Table 1). This correction was then applied to all dust wipes that did not undergo ICP-MS analysis to improve total data accuracy (ESI Tables S4–S6†).

### 4. Discussion

Correlation analysis of trace metals analysed using ICP-MS and pXRF across the three case studies revealed a reliable relationship between the analytical methods, ranging from moderate to strong correlations ($r = 0.489–0.956$; $p < 0.01$). Applying a correction formula to pXRF data from a limited subset of samples (~30%) analysed with ICP-MS markedly enhanced the quality of the data (Fig. 4 and Table 1). Notwithstanding the positive outcome, the user needs to consider several benefits and limitations regarding the application of this method, as discussed below.

#### 4.1. Benefits and limitations of pXRF analysis on dust wipes

Based on the results presented above, using pXRF for dust wipe analysis offers several advantages.

Application of the pXRF method provides greater opportunity for targeted sampling approaches and campaigns where decision-making is required promptly.49 Analysis of dust wipes using pXRF provides end users with an opportunity to evaluate and screen sampled surfaces near in situ. The correlations between pXRF and ICP-MS dust wipe pre-correction (see Section 3.2) highlight pXRF’s potential to provide reliable and expedited screening results for dust wipe samples. However, using post-measurement correctional formulas and adjusting testing times, as described here, can evidently lead to even more precise and accurate results (see Section 3.3). An initial sampling set to establish correctional formulas could be sufficient in a small area like Tsumeb or Thio, where the effects of dominant industrial activities like metal mining or smelting might be concentrated. By contrast, in a larger city with potentially multiple contamination sources, more samples may need to be collected and analysed using ICP-MS to discern spatial patterns and identify the influence of various sources.

Given that supplementary ICP-MS analysis is only required for ~30% of dust wipes collected, using pXRF can also mitigate the often-limiting financial costs associated with research, and allow for a more detailed sampling campaign. Adopting pXRF as the primary analytical method has yielded reliable results in settled vacuum dust10 and robust information for empowering...
Fig. 4  Linear regression plots showing the adjustment or correction of data of Pb in Tsumeb (pre (a) and post (b) correction), Nouméa (pre (c) and post (d) correction) and Thio (pre (e) and post (f) correction). The correctional equations were applied to additional data of analysed pXRF dust wipes that did not undergo ICP-MS analysis as a further example of the application of this method, which can be seen in ESI Tables S4–S6.† The linear regression of the remaining trace metals is provided in ESI Fig. S4–S6.†
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community-led scientific initiatives relating to soil and dust contamination. Its application has significantly enhanced the feasibility of contaminant site assessments and intervention actions, and presents a low-cost and reliable alternative to traditional assessment.

While it is evident there is value and utility in using pXRF for the measurement of trace metals in deposited dust (Table 1 and Fig. 1), several limitations need to be considered. This includes the perception that pXRF is an initial ‘screening’ tool rather than a ‘gold standard’ or well-accepted analytical approach. The case studies presented above demonstrate that when applied appropriately, and validated correctly, pXRF data can be corrected to provide results of comparable quality to ICP-MS. Furthermore, it is important to note that while minor variations between separate instruments may exist, thorough quality assurance processes and development of linear regression equations should be sufficient to address instrument differences.

Other limitations include that while ICP-MS analysis consists of digesting the whole wipe, the non-destructive pXRF method measures various points of the wipe, providing estimated concentrations across the whole area, which may lead to minor data discrepancies. Analytical quality may decrease in samples with low trace element concentrations (due to the relatively high LOD of pXRF compared to ICP-MS), or in wipes with uneven dust distribution if the variance is not captured by the quadrant analysis. Lastly, correctional equations are unique for each locality, meaning that ICP-MS analysis is always needed on a subset of dust wipes to produce high-quality data, and correctional equations should not be applied across different projects. Therefore, the pXRF method described here does not replace ICP-MS (or similar) analysis but rather complements it.

4.2. Contextualising risk using dust wipe data

Established standards exist for Pb loading measurement on indoor residential floors. Equivalent standards are absent for other trace metals, with the notable exception being the TA Luft, which provides loading limits for As, Cd, Pb, Ni, mercury (Hg), and thallium (Tl) expressed as a daily loading value averaged over a year (µg m⁻² day⁻¹). Comparison to TA Luft values thus requires a sampling design that measures the duration of dust accumulation on the wiped surface, so that a daily loading rate can be estimated.

In this study, corrected indoor dust wipe sample data (n = 23) from the Thio campaign were compared against the relevant United States Environmental Protection Agency’s Dust Lead Clearance Levels (DLCL) standards for floor dust Pb (ESI Table S6f). Four of the 23 homes sampled had loadings above the DLCL (108 µg m⁻²), indicating potential environmental health risks due to Pb contamination.

These results indicate that pXRF can effectively assess Pb loadings in dust wipes and determine whether they meet established standards. Furthermore, the data in this study provide useful loading data for a range of trace metals that can be compared to different areas or localities to understand environmental health risks beyond Pb contamination.

5. Conclusions

The proposed pXRF method for dust wipe analysis provides a practical and cost-efficient solution for assessing exposure to potentially contaminated environments. Based on the results, pXRF delivered favourable trace metal concentration analysis in dust wipes, noting the following observations:

An optimal balance between precision and time efficiency was achieved by performing four tests per wipe on pXRF, as significant data variations were not observed beyond this point. Furthermore, pXRF data without any correction showed moderate to strong correlations ($R^2 = 0.432–0.989$) with ICP-MS data, highlighting its viability as a reliable analytical option. Subsequently, most pXRF coefficients of variation calculated were suited for quantitative screening purposes. Correction plots demonstrated that pXRF data quality can improve considerably by using a subset of samples (~30%) analysed using ICP-MS to post-correct data from a given case study.

Factors such as the inherent increase in data variability for trace metals at concentrations nearing pXRF LOD, and the need for ICP-MS data and correction equations to be generated for individual case studies should be considered when applying this approach. However, as has been demonstrated above, pXRF analysis offers a robust approach, that when used correctly and when enough background knowledge is gathered, returns dust wipe data comparable to traditional ICP-MS analysis. The use of pXRF enables increased sampling density at minimal additional cost, and allows for rapid decision making on the contamination status and risk from trace metals in areas of interest. Future studies could investigate the reliability of a wider range of trace metals to fully understand the capabilities and limitations of pXRF in environmental sampling.

Conflicts of interest

There are no conflicts to declare.

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