

# On-site elemental analysis of environmental waters using portable XRF

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**Abstract** Rapid on-site detection of metals in water is essential for timely environmental assessment, especially in remote areas or time-critical situations. In this work, we present a portable measurement system that combines preconcentration filters with a portable X-ray fluorescence (pXRF) analyzer. Filters for Mn, Co, Ni, Cu, Zn, Pb, and U were fabricated using nanoporous silicon or silicon carbide with polymeric binders, while arsenic was captured using ferrihydrite-based filters. Water samples were collected from lakes, boreholes, and wells, and measured on-site. Detection limits as low as 12 µg/L for metals and 1.3 µg/L for arsenic were achieved, depending on sample volume. Results were validated against laboratory ICP-MS analysis. The lightweight, battery-operated setup enables field deployment with total measurement times as short as 15 minutes, offering a practical tool for preliminary screening and environmental monitoring in challenging conditions.

**Keywords:** On-site metal analysis, Portable XRF, Water quality monitoring, Trace metals detection

## 1. Introduction

Heavy metals in water sources can pose significant risks to both the environment and human health, making their monitoring an important part of water quality assessment. Detecting metals such as lead, copper, and zinc is essential for understanding potential contamination in natural and industrial waters.

Currently, metal analysis is typically performed using laboratory-based techniques such as inductively coupled plasma mass spectrometry (ICP-MS) or atomic absorption spectroscopy (AAS). While these methods offer high sensitivity and accuracy, they are often expensive, require trained personnel, and involve considerable delays between sample collection and results due to transportation and processing times.

In this work, we demonstrate how a combination of preconcentration techniques and portable X-ray fluorescence (pXRF) analysis can be used to assess metal concentrations in water directly at the sampling site. The

approach is designed to be fast, field-compatible, and suitable for applications where rapid screening and ease of use are prioritized.

## 2. Methods

Two types of preconcentration filters were used to enable on-site measurement of metals from water samples. Filters targeting Mn, Co, Ni, Cu, Zn, Pb, U were fabricated using high-surface-area nanoporous silicon or silicon carbide (nSiC) particles functionalized with bisphosphonates. The particles were bound together with polymeric binders—carboxymethyl cellulose (CMC) and polyacrylic acid (PAA). For arsenic (As) measurements, the filters consisted of ferrihydrite powder sandwiched between two layers of filter paper.

Water samples were collected from a variety of natural sources, including lakes, mineral exploration boreholes, and wells. A syringe pump was used to pass the water through the preconcentration filters. After filtration, the metal-loaded filters were analyzed using a portable Olympus DPO-2000C X-ray fluorescence (XRF) analyzer.

Reference concentrations for each sample were determined using a PerkinElmer NexION 350D inductively coupled plasma mass spectrometer (ICP-MS). Empirical calibrations for each target element were established by correlating XRF signal intensities with the corresponding ICP-MS results.

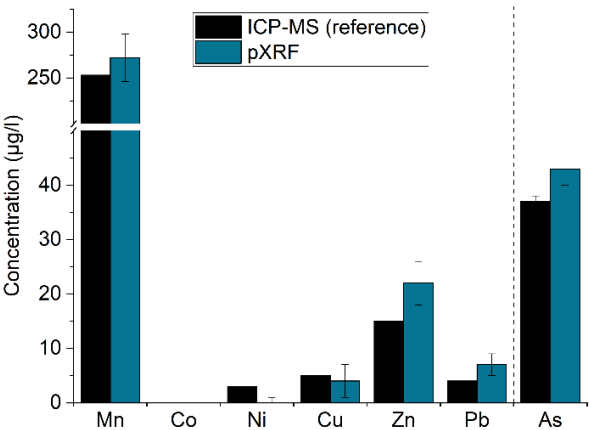
## 3. Results and Discussion

### 3.1. On-Site Measurements of Metals

The developed system successfully enabled the detection of Mn, Co, Ni, Cu, Zn, Pb, and U in a variety of water samples using preconcentration filters and portable XRF analysis. A comparison between results obtained with XRF and ICP-MS is presented in Figure 1. Detection limits (LoDs) were dependent on the sample volume. The best LoDs—down to 12 µg/L—were achieved with 100 mL sample volumes and 100 minutes of filtration.

More practical filtration times of 10 minutes with 10 mL volumes still enabled LoDs as low as 35 µg/L, making the method suitable for rapid field assessments (see Table 1).

Filter material properties also influenced detection performance. Filters made with smaller nanoporous silicon carbide (nSiC) particles yielded slightly better LoDs than those made with larger porous silicon particles. This is likely due to increased tortuosity in the flow path, improving metal capture efficiency.



**Figure 1.** Concentration of elements measured with pXRF from preconcentration filters compared with ICP-MS results. Mn, Co, Ni, Zn and Pb were measured from a groundwater around an ore deposit with nSiC filters. The arsenic was measured from a different groundwater sample using a ferrihydrite filter.

**Table 1.** Limits of detection (LoD) for elements and the sample volume used.

Element	LoD (µg/l)	V (ml)	Ref.
Mn	103	10	Tiihonen 2022
Mn	12	100	Rahmani 2024
Co	16	100	Rahmani 2024
Ni	86	10	Tiihonen 2022
Ni	15	100	Rahmani 2024
Cu	92	10	Tiihonen 2022
Cu	19	100	Rahmani 2024
Zn	35	10	Tiihonen 2022
Zn	16	100	Rahmani 2024
Pb	44	10	Tiihonen 2022
Pb	18	100	Rahmani 2024
U	43	10	Tiihonen 2022
As	9	20	Unpublished.
As	1.3	200	Unpublished.

Matrix effects were also observed, particularly for Mn. Elevated calcium and magnesium concentrations in the water matrix were found to reduce the retention efficiency of the filter, highlighting the need to account for competing ions in real-world applications.

### 3.1. On-Site Measurements of Arsenic

Ferrihydrite-based filters proved effective for arsenic preconcentration in groundwater samples (Figure 1). The method achieved LoDs as low as 1.3 µg/L (see Table 1). The capture efficiency was influenced by the surface area of the ferrihydrite used, with higher surface areas yielding improved performance.

### 3.2 System Usability and Field Suitability

The complete system—including filtration apparatus and portable XRF analyzer—can be battery operated and weighs under 10 kg, supporting mobility and ease of deployment. Depending on filtration volume, the entire measurement process can be completed in as little as 15 minutes.

The method is particularly well suited for time-sensitive field applications, including rapid response to environmental incidents, smart sampling for locating contamination sources, and preliminary screening in remote areas with limited infrastructure.

## 4. Conclusions

We demonstrated a portable, field-compatible system for on-site detection of trace metals in water using preconcentration filters and handheld XRF analysis. The method enabled quantification of Mn, Co, Ni, Cu, Zn, Pb, U, and As with detection limits down to low µg/L levels, depending on the measured element, and filtration volume. Filter material properties and water matrix composition were also found to influence measurement performance.

The system is lightweight, battery-operable, and capable of delivering results within 15–110 minutes, depending on the application needs. These features make it particularly suitable for rapid screening, smart sampling, and use in areas with limited infrastructure.

## 5. References

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