Surface and tap water quality in Cerro de Pasco and surrounding areas

Report on water contamination • July 2024 campaign

Cerro de Pasco, Peru

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Executive summary

Cerro de Pasco, one of the world's highest cities, has been profoundly reshaped by centuries of extractive activities. In the 1900s, the expansion of open-pit operations radically transformed both the city and its surroundings, leaving a legacy of widespread environmental contamination. Despite repeated declarations of health and environmental emergencies, residents continue to face chronic exposure and associated illnesses, making Cerro de Pasco a stark emblem of mining-related environmental injustice.

This report presents the results of the last independent environmental monitoring campaign conducted by Source International in collaboration with Centro de Cultura Popular Labor and Red Interquorum Pasco. In July 2024, we collected 9 surface water samples from Lake Quiulacocha, Lake Yanamate, the Tingo River, and the San Juan River watershed, alongside 2 tap waters from the city of Cerro de Pasco. All samples were analyzed and evaluated against the most recent Peruvian normative and past monitoring campaigns from 2022 and 2023.

The analyses confirmed **widespread contamination of surface waters**, with 32 exceedances of the Environmental Quality Standards (EQS) for aquatic ecosystems, 25 of the EQS for agricultural use, 22 of the EQS for livestock use, and 10 for mining effluent regulations. Lake Quiulacocha and Lake Yanamate were the most polluted sites, with **aluminum, cadmium, iron, manganese, lead, copper, thallium, and zinc reaching concentrations tens to thousands of times above legal thresholds**. Samples from the San Juan River and Tingo River watersheds also showed multiple exceedances near known pollution sources. Although trends over time suggest a modest decline in contamination at some sites and for some parameters since 2022, concentrations remain high and concerning. **Cadmium, zinc, manganese, and high conductivity were the most persistent issues across all sites and years.**

Tap water quality was overall acceptable, with only one minor exceedance for iron – an organoleptic parameter not directly related to safety. This finding aligns with previous years and indicates that municipal supplies in the San Juan and Paragsha districts currently pose a lower immediate risk compared to surface waters.

The persistence and extent of heavy metal pollution in Cerro de Pasco and its surroundings pose acute risks for both human health and ecosystems. Cadmium and lead – classified as major public health concerns by the World Health Organization and as Class 1 and 2A carcinogens by the International Agency for Research on Cancer – remain at critical levels in surface waters. Even essential elements like zinc and manganese occur at unsafe concentrations. **Cerro de Pasco thus remains one of the most severely polluted mining areas in the world**. Without decisive remediation and stronger protective measures, this contamination will continue to threaten the well-being of local communities and the integrity of downstream ecosystems for years to come.

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Introduction

The context

Cerro de Pasco, one of the highest altitude cities in the world, has been at the center of large-scale extractive activities for centuries. During the 20th century, the expansion of open-pit mining dramatically reshaped the urban and natural landscape (Figure 1 and Figure 2) – displacing neighborhoods, draining lakes, and exposing vast areas of soil, water, and sediments to heavy metal contamination. Quiulacocha and Yanamate are emblematic of these impacts (Figure 2): originally natural lakes ("Quiulacocha" is named after the Andean gulls that once lived on its shores[1]), since the 1980s, they have served as discharge sites for untreated tailings, leading to the complete disruption of their ecosystems.

Since 2008, Source International has supported local partners in documenting the **widespread environmental contamination generated by Cerro de Pasco's open-pit mine and its associated activities**.[2–5] Multiple lines of evidence highlight the exceptional severity of this pollution. These include, among others, the highly acidic pH of the lakes and extreme concentrations of dissolved metals – often thousands of times higher than national and international regulatory standards. The contamination is especially evident in soil and surface water, where elevated levels of lead, cadmium, zinc, manganese, and other toxic metals have been constantly detected.[4,5]

The health implications of this pollution are profound. Clinical and biomonitoring studies indicated that **virtually all children in Cerro de Pasco carry detectable levels of heavy metals in their blood, urine, and hair, often exceeding international reference thresholds**.[5–8] Lead, cadmium, and arsenic are the most prevalent,[5,7,8] and their presence is closely linked to the significantly lower IQ scores among Cerro de Pasco's children as compared to nearby control communities.[7] Despite the National Ministry of Health declaring a health emergency and being informed of the situation,[9] children in Cerro de Pasco continue to suffer – and even die – from chronic exposure to these toxic metals, with the most recent reported fatality occurring in early 2025.[10]

Figure 1. Aerial view of "El Tajo", the large open-pit mine around which Cerro de Pasco has grown. Photo credit: Stefano Sbrulli for Source International, 2019.

Figure 2. Aerial view of Lake Quiulacocha's blood-red waters from close to the eponymous community. Photo credit: Stefano Sbrulli for Source International, 2019.

The report

In this fragile context, documenting the state of environmental resources and the health of the local community is both a social and ethical imperative. Building on over a decade of work in the region, in July 2024, Source International conducted a **new independent monitoring campaign focused on surface and tap waters in Cerro de Pasco and surrounding areas**. These data add to the **growing body of evidence of water contamination** from the local mining industry, reinforcing findings from previous samplings conducted in 2008,[3] 2016,[11] 2019,[5] 2022,[12] and 2023[13].

This report describes the results of the July 2024 campaign, providing an updated basis to support forthcoming legal actions. All data are discussed in the context of the most recent regulatory standards set by the Peruvian Ministry of Environment and Ministry of Health and compared to the two prior monitoring campaigns from 2022 and 2023 (a more thorough assessment including also previous years is ongoing).

Normative reference

In this report, we used the most updated regulations by the Peruvian Ministry of Environment (MINAM) and the Ministry of Health (MINSA; Table 1). For surface waters, we referred primarily to the **Peruvian Environmental Quality Standards** (EQS) established by the Supreme Decree N˚004-2017-MINAM.[14] We focused on the EQS for the conservation of aquatic environments (category 4, subgroups E1 and E2), which apply to lakes (E1) as well as to coastal and inland rivers located 600 m above sea level (E2). Since the variables of interest have the same value in the two subcategories, we present them together in Table 1 and consider them as a single category in the text.

Table 1. Overview of the normative reference used for evaluating environmental quality. Heavy metals not listed in this table are not regulated under the current normative. Columns in grey are not used as primary reference in the text. [a] Value in each moment, not yearly. [b] Organoleptic water quality parameters.

Parameter	D.S. N˚004-2017-MINAM		D.S. N˚010-2010-MINAM	D.S. N˚031-2010-MINSA
	Lakes and rivers (E1/E2)	Agriculture and farming (D1/D2)	Mining effluents[a]	Water for human use
pH	6.5 – 9	6.5 – 8.5	6 – 9	6.5 – 8.5[b]
Conductivity	1000 µS/cm	2500 µS/cm	–	1500 µS/cm[b]
Aluminum	–	5000 µg/L	–	200 µg/L[b]
Antimony	640 µg/L	–	–	20 µg/L
Arsenic	150 µg/L	100 – 200 µg/L	100 µg/L	10 µg/L
Barium	700 µg/L	700 µg/L	–	700 µg/L
Beryllium	–	100 µg/L	–	–
Boron	–	1000 – 5000 µg/L	–	1500 µg/L
Cadmium	0.25 µg/L	10 – 50 µg/L	50 µg/L	3 µg/L
Cobalt	–	50 – 1000 µg/L	–	–
Chromium	–	100 – 1000 µg/L	–	–
Iron	–	5000 µg/L	2000 µg/L	300 µg/L[b]
Manganese	–	200 µg/L	–	400 µg/L[b]
Mercury	0.1 µg/L	1 – 10 µg/L	2 µg/L	1 µg/L
Molybdenum	–	–	–	70 µg/L
Nickel	52 µg/L	200 – 1000 µg/L	–	20 µg/L
Lead	2.5 µg/L	50 µg/L	200 µg/L	10 µg/L
Copper	100 µg/L	200 – 500 µg/L	500 µg/L	2000 µg/L[b]
Selenium	5 µg/L	20 – 50 µg/L	–	10 µg/L
Thallium	0.8 µg/L	–	–	–
Zinc	120 µg/L	2000 – 24000 µg/L	1500 µg/L	3000 µg/L[b]

For tap waters, we compared the results with the **Peruvian Maximum Permissible Limits** (MPLs) defined in the Supreme Decree N˚031-2010-MINSA.[15] This normative regulates the chemical and microbiological composition of water intended for human and domestic use, specifying limits for organoleptic characteristics (Annex II), organic and inorganic contaminants (Annex III), and microbiological parameters (Annex I).

To further contextualize our findings, we considered two additional frameworks. First, the category 3 EQS from the Supreme Decree N˚004-2017-MINAM, which cover water for irrigation and livestock.[14] These standards are generally less stringent than category 4 and are particularly relevant for samples collected near farming or agricultural activities. Second, the MPLs for industrial effluents from mining activities established in the Supreme Decree N˚010-2010-MINAM.[16] Although these limits apply only to a subset of chemicals, they provide a useful benchmark for evaluating overall pollution levels at sites affected by mining operations and/or known to be close to mining effluents. All relevant limits are summarized in Table 1 (grey values).

Sampling site and methods

Sampling sites

Sampling took place on July 18, 2024, in Cerro de Pasco and its surroundings. The 2024 investigation focused on water and involved the collection of 9 surface waters and 2 tap waters, for a total of 11 samples (Figure 3). The sites were selected based on previous years' experience.[12,13]

For surface waters, we worked in 3 areas. First, we sampled 3 sites along the Tingo River, beginning at its spring below the Rumiallana stockpile (TR1) and continuing northward to TR2 and TR3, located approximately 2.1 and 3.8 km downstream of TR1. The stockpile includes both mining and municipal waste.[13] Second, we investigated 5 sites on the southwest side of Cerro de Pasco (Figure 3A), including Lake Quiulalocha (Q1) and 4 other locations within the San Juan River basin (S1 to S4). Specifically, S1 was collected along the Ragra River and received discharges from the nearby mine. S2 was taken directly from an Ocroyoc tailing dam effluent before it merged into the Ragra River. S3 was located further downstream along the Ragra River, near the Yurajhuanca community. S4 was taken on the San Juan River upstream of the Aurex gold mine. The last surface water sample was collected in a southern arm of Lake Yanamate (Y1), near the 2022 sampling point.[12]

Tap water was sampled in 2 locations in Cerro de Pasco. Sample P1 was from a domestic tap near the main square in Paragsha, while SJ1 was collected in the Señorial Hotel in the San Juan district – the only part of the city currently supplied with clean water.

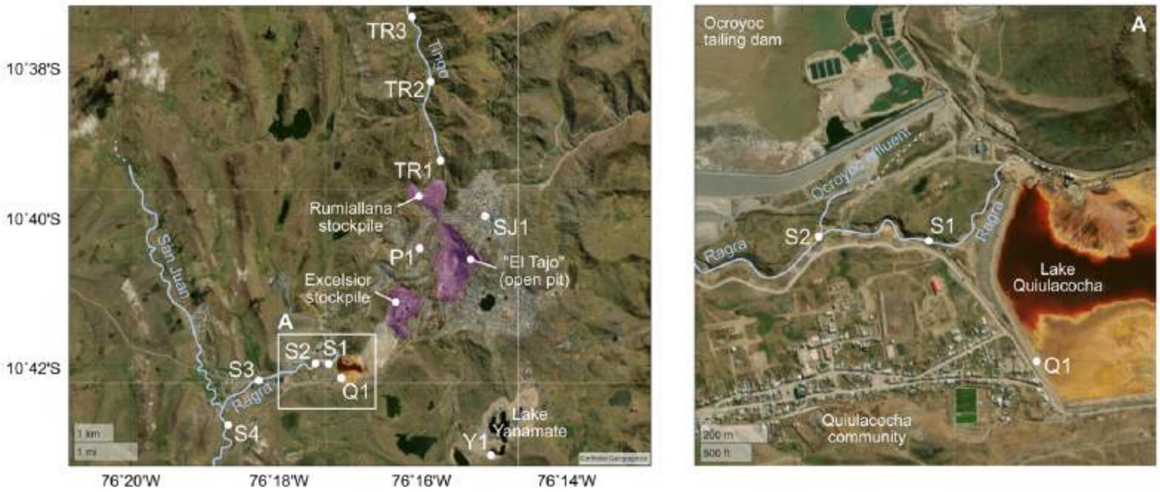

Figure 3. Overview of sampling locations. The violet highlights show some key landscape elements of Cerro de Pasco's mining legacy that are mentioned in the text. Panel A shows a zoom of Lake Quiulacocha and surrounding areas. The highlight of the rivers is approximate. The map was obtained from Matlab (R2021b) and does not necessarily reflect the conditions during sampling.

Figure 4. Overview of sampling activities and tools. Panels A and B show the use of the multiparametric probe in the Tingo River and Lake Yanamate. Panels C and D show how we collected surface waters using the Teflon sampler at the Lake Quiulacocha and the Tingo River.

General site and water characterization

At each site, we recorded the GPS position with a Garmin Fenix 7 watch and measured general water quality parameters with a multiparametric field probe (Hanna, HI 98194). The probe's pH and conductivity sensors were calibrated prior to sampling with new standard solutions (i.e., commercial buffers at pH 4 and 7 for pH and a 1413 µS/cm standard solution for conductivity). The temperature probe was used uncalibrated. For measurements, we placed the multiparametric probe in running water (Figure 4A-B) and recorded temperature, pH, and conductivity values after stabilization. We then rinsed the probe thoroughly with deionized water and stored it in its case. For tap waters, we placed the liquid sample into a container and recorded the same parameters after stabilization.

Water sampling

We collected surface waters using a teflon sampler equipped with a 50 cm stick (Figure 4C-D). The sampler was rinsed thoroughly with surface water, then we syringe-filtered (0.45 µm) the water directly into a new 50 mL falcon tube. We added 4 drops of concentrated nitric acid (70%), mixed, labeled, and stored away from direct sunlight. Tap water samples were collected in a rinsed plastic bottle and then subjected to the same treatments as surface waters.

At the end of the sampling day, we stored all waters at room temperature. During national and international transports, samples stayed at room temperature in the dark.

Chemical analyses

Heavy metal analysis in water was performed by an accredited laboratory (certified by ACCREDIA) within 20 days of collection. We analyzed 21 heavy metals following the procedure UNI EN ISO 17294-2:2023 (inductively coupled plasma mass spectrometry). Table A1 reports the limits of detection (LoD) and average estimated measurement uncertainties as provided in the laboratory's test reports.

Data analysis

We analyzed all data with Excel and Matlab (R2012b). We computed boxplots and medians using all available concentrations, also when the analyte was not detected (n.d.; value set to 0) or was below its limit of detection (raw data in Table 3). We performed exploratory principal component analysis (PCA) in Matlab inputting standardized data matrices (via the "zscore" function) into the "pca" function.

For obtaining the maps, we converted GPS locations in degrees, minutes, and seconds as provided by the Garmin watch into decimal degrees (DD) using the following equation.

$$\mathrm{DD} = \mathrm{degrees} + \frac{\mathrm{minutes}}{60} + \frac{\mathrm{seconds}}{3600}$$

Past sampling

In this report, we primarily compare our results with the two most recent campaigns, which took place in October 2022[12] and August 2023[13]. Although the sampling areas largely overlapped, historic data are not available for all sites visited in July 2024 (Table 2, surface waters only). Tap water was analyzed in both previous years but the specific sampling points varied every time. For this reason, results for tap water are discussed only in an aggregated form.

Table 2 Overview of data availability for the past two sampling campaigns. The text in parenthesis indicates the sample name in the respective report. Locations may differ slightly from those visited in 2024.

Sample ID (2024)	TR1	TR2	TR3	Q1	S1	S2	S3	S4	Y1
2022	x (A10)	x (A9)		x (A8)	x (A13)		x (A5)		x (A11)
2023	x (A1)	x (A2)		x (A9)			x (A5)		

Results

General water chemistry parameters

Water pH ranged from 2.4 to 8.4, although most values were between 6.5 and 8 (Figure 5A and Table A2). Lake Quiulacocha (Q1) and Lake Yamamate (Y1) had pH values well below any regulatory limit (Table 1). Both sites have a well-documented history of acidic contamination from mining residues and consistently exhibited strongly acidic conditions in past campaigns.[3,5,12]

Conductivity spanned from 154 to 13150 µS/cm (Figure 5B and Table A2). Except for the two tap waters, which were below all normative limits, **8 of 9 surface waters exceeded the EQS for the protection of aquatic ecosystems** (Table A2). Q1 had the highest conductivity of the dataset and was clearly identified as an outlier in the boxplot analysis (Figure 5B). Likewise, Y1 showed elevated conductivity (2740 µS/cm), ranking second overall and exceeding the EQS for more permissive classes (e.g., cat. 3). These two sites had conductivity above 4000 µS/cm also in 2022,[12] in agreement with the known contamination.

Water temperature was between 6.7 and 21 °C (median of 13 °C), consistent with climate conditions in Cerro de Pasco. The boxplot analysis identified two outliers: Lake Quiulacocha (Q1) and the Paragsha tap water (P1), which were respectively warmer and colder than the rest of the samples. We suspect Lake Quiulacocha's higher temperature may be caused by the oxidation of pyrite by oxygen, iron, and microbes – a process that is known to release heat.[17,18] Indeed, pyrite, a mineral made of iron and sulfur, constitutes approximately 50% of Lake Quiulacocha's tailing residues.[19]

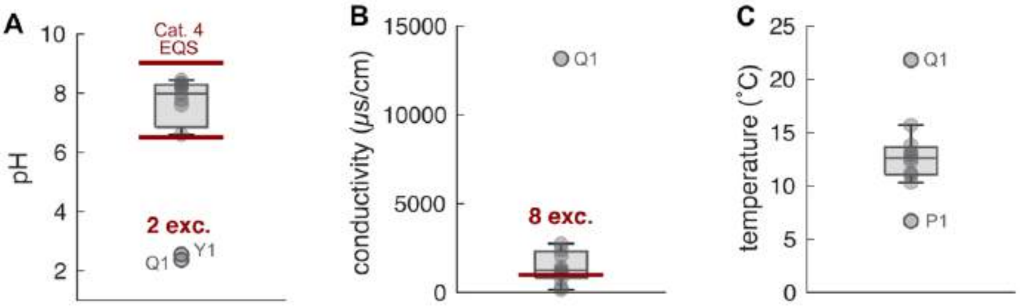

Figure 5. Overview of general water chemistry parameters (*N* = 11). The red line in panels A and B indicate the category 4 Peruvian Environmental Quality Standard (EQS), while the red text clarifies the number of exceedances (exc.). Raw data are in the Appendix (Table A2).

Overview of heavy metals in water

Of the 21 analyzed, we detected 20 metals, of which 11 in all samples (Table 3). In addition to naturally ubiquitous elements – such as iron, aluminum, and manganese – all waters contained antimony, arsenic, barium, boron, nickel, copper, and zinc above their limits of detection. Mercury was never detected, while beryllium, cobalt, chromium, molybdenum, selenium, tin, and vanadium exceeded their detection limits only in a handful of sites (Table 3). This distribution of metals mirrors

Table 3. Heavy metal concentrations in water (in µg/L) and relevant national normative. For surface water, we primarily refer to the cat. 4 Environmental Quality Standards (EQS). The cat. 3 EQS and the Maximum Permissible Limits in mining effluents (ME) are reported at the bottom as a secondary reference. For drinking water, we report the Maximum Permissible Limits for human use (HU). Cells with concentrations exceeding cat. 4 EQS or HU are highlighted in dark red, while cells with values above one or more of the other reference normative are grey. Values in grey were either not detected ("n.d.", reported as zeros by the laboratory) or below their limits of detection (values in Table A1). All concentrations are in µg/L.

Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Cobalt	Chromium	Iron	Manganese	Mercury	Molybdenum	Nickel	Lead	Copper	Selenium	Tin	Thallium	Vanadium	Zinc
Surface water																					
RT1	82	0.73	3.8	14	n.d.	92	0.19	0.50	n.d.	**350**	**520**	n.d.	1.5	2.9	1.5	11	0.62	0.19	n.d.	0.39	**170**
RT2	6.1	0.51	3.4	13	n.d.	63	n.d.	0.38	n.d.	**2200**	**700**	n.d.	0.65	1.4	0.44	2.5	0.27	n.d.	n.d.	0.21	73
RT3	25	0.45	2.3	20	n.d.	56	**0.32**	0.52	n.d.	230	**1700**	n.d.	0.95	1.9	0.64	2.0	0.39	n.d.	0.41	0.16	**1100**
Q1	**17000**	0.73	**450**	2.6	3.7	120	**460**	**58**	13	**1300000**	**800000**	n.d.	n.d.	**190**	**65**	**3200**	1.9	0.16	**28**	4.5	**540000**
S1	22	0.96	9.4	170	n.d.	43	**0.28**	0.40	n.d.	840	**1500**	n.d.	0.37	1.5	0.92	3.6	n.d.	n.d.	0.50	n.d.	**540**
S2	88	0.48	1.9	30	n.d.	44	**1.2**	5.1	n.d.	220	**14000**	n.d.	0.27	5.8	1.9	13	1.1	n.d.	**3**	n.d.	**250**
S3	41	1.1	10	18	n.d.	38	n.d.	0.37	n.d.	140	**1300**	n.d.	0.3	5.0	1.1	7.5	0.21	n.d.	0.58	n.d.	**240**
S4	43	1.2	10	19	n.d.	36	0.11	0.41	n.d.	130	**1300**	n.d.	0.43	2.2	1.6	7.5	n.d.	n.d.	0.46	n.d.	**210**
Y1	**7400**	2.2	32	4.5	0.65	47	**24**	6	1.3	**53000**	**7900**	n.d.	n.d.	14	**25**	**460**	0.33	n.d.	**12**	n.d.	**14000**
Cat. 4 EQS		640	150	700			0.25					0.1		52	2.5	100	5		0.8		120
Cat. 3 EQS (D1)	5000		100	700	100	1000	10	50	100	5000	200	1		200	50	200	20				2000
Cat. 3 EQS (D2)	5000		200		100	5000	50	1000	1000		200	10		1000	50	500	50				24000
ME			100				50			2000		2			200	500					1500
Drinking water																					
P1	100	1.7	4.8	32	n.d.	19	n.d.	n.d.	n.d.	**310**	32	n.d.	0.49	0.34	2.4	3.3	0.12	n.d.	n.d.	0.14	46
SJ1	30	0.73	3.8	7.8	n.d.	16	n.d.	n.d.	n.d.	190	22	n.d.	0.36	0.37	2.7	7.8	n.d.	n.d.	n.d.	n.d.	16
HU	200 ^{a}	20	10	700		1500	3			300 ^{a}	400 ^{a}	1	70	20	10	2000 ^{a}	10				3000 ^{a}

well what we found in 2022 and 2023.[12,13]

When considered in the context of the Peruvian regulations, **zinc and cadmium showed the most frequent exceedances**, with 7 and 5 values, respectively, surpassing the Peruvian Environmental Quality Standards for the protection of aquatic life (Table 3). All surface water samples exhibited also significantly high levels of manganese (500 – 800000 µg/L) and iron (130 – 1300000 µg/L). Although these metals are not included in the Peruvian EQS for the protection of aquatic ecosystems, normative values exist for water used for livestock and human consumption, and in mining effluents (Table 1). By these standards, **manganese in surface waters exceeded legal limits in 100% of the samples**, while iron surpassed all applicable limits in 2 samples and exceeded the limit for mining effluents at 2 additional sites (Table 3).

Most exceedances occurred in Quiulacocha and Yamamate (Q1 and Y1). In contrast, the tap waters were of overall good quality, with only a single exceedance for iron in P1 (310 µg/L vs. the Maximum Permittable Level of 300 µg/L; Table 3). An exploratory principal component analysis confirmed that Q1 and Y1 had a significantly different chemical composition than the others, while tap waters were overall similar to the samples collected in the San Juan River watershed (Figure A1).

Below, we discuss in detail the composition of samples collected in the two lakes (Q1 and Y1), along the Tingo River (TR1 to TR3), within the San Juan River watershed (S1 to S4), and in Cerro de Pasco's taps (P1 and SJ1). When possible, this new data is contextualized with the results of the 2022 and 2023 water monitoring data.

Lake Quiulacocha

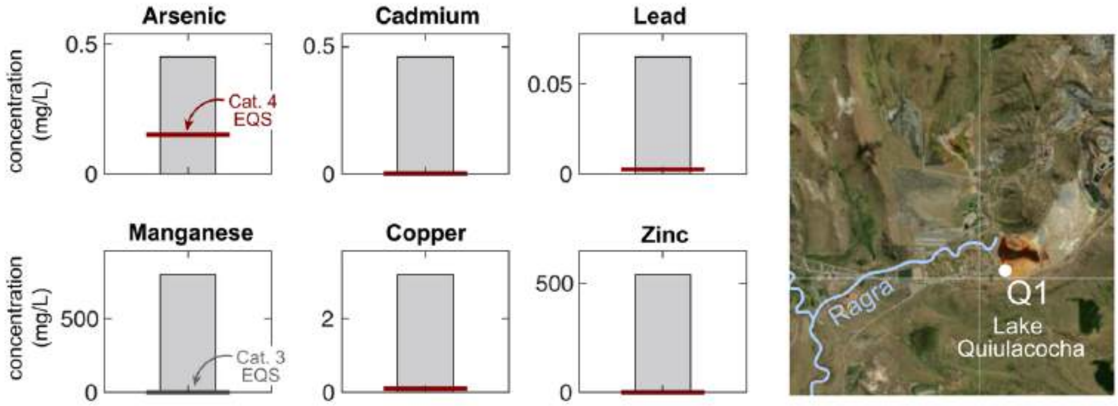

Figure 6. Exceedances of selected heavy metals in Lake Quiulacocha. The dark red and grey lines indicate, respectively, the cat. 4 and 3 (subcategory D1; shown only for manganese) Environmental Quality Standards (EQS) for Peru (details in Table 1). Raw data are Table 3. The map on the right is a reproduction of Figure 3 that clarifies the location of the sampling site.

Lake Quiulacocha presented exceptionally high levels of dissolved metals. **Almost all elements regulated under the D.S. N˚008-2017-MINAM exceeded their normative limit, for a total of 7 exceedances of the EQS for the protection of aquatic life** (Figure 6 and Table 3). Specifically, arsenic was 3 times higher than the EQS (450 vs. 150 µg/L), cadmium was 1840 times higher (460 vs.

0.25 µg/L), nickel was almost 4 times higher (190 vs. 52 µg/L), lead was 26 times higher (65 vs. 2.5 µg/L), copper was 32 times higher (3200 vs. 100 µg/L), thallium was 35 times higher (28 vs. 0.8 µg/L), and zinc was 4500 times higher (540000 vs. 120 µg/L). Although not regulated in cat. 4, aluminum, iron, manganese, and cobalt were above the cat. 3 EQS, yielding **4 more exceedances** (Table 3). Arsenic, cadmium, iron, and copper were also above the normative limits for mining effluents (Table 3).

These findings agree well with results from the 2022 campaign[12] (this site was not sampled in 2023; see Table 2). **Almost all metals that exceeded the EQS for the protection of aquatic life in 2024 did so also in 2022**; as the only exceptions, lead and thallium were below the limit of detection in 2022 but above the cat. 4 EQS in 2024, while selenium exceeded the standard in 2022 (8.4 µg/L vs. 5 µg/L) but not in 2024. Likewise, aluminum, iron, and manganese exceeded the cat. 3 EQS also in 2022. Overall, these results indicate **sustained contamination of the lake throughout the years**. Among the detected elements, arsenic, cadmium, and lead are particularly concerning due to their toxic effects also at low concentrations.[20] While arsenic, lead, and thallium have fluctuated during the years, **cadmium has always been exceptionally high** (790 µg/L in 2022 and 640 µg/L in 2024, at least 2 orders of magnitude higher than its EQS of 0.25 µg/L).

Lake Yanamate

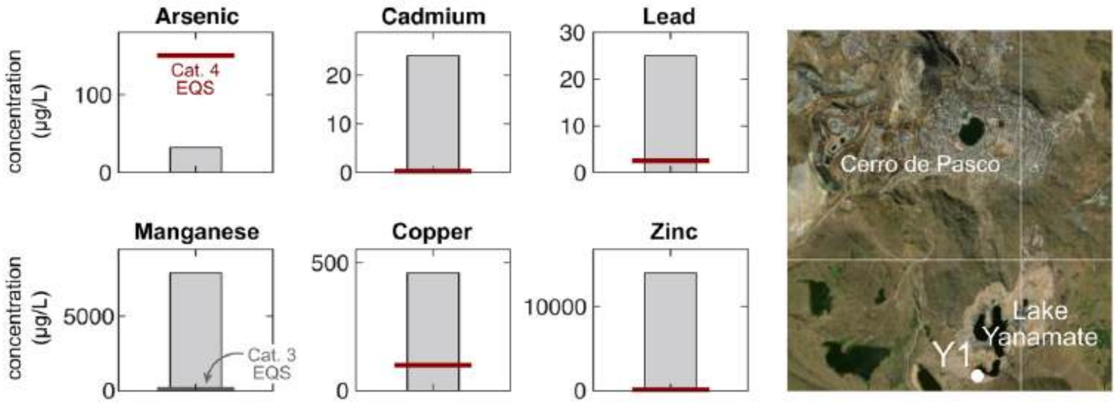

Figure 7. Exceedances in selected heavy metal in Lake Yanamate. The color code is the same as in Figure 6. Raw data are in Table 3.

Lake Yanamate (Y1) was the second-most polluted site after Q1, with **5 exceedances of the Peruvian EQS for the protection of aquatic ecosystems** (Figure 7 and Table 3). Metals above the cat. 4 EQS included cadmium (24 µg/L, 96 higher than the EQS), lead (25 µg/L, 10 times higher), copper (460 µg/L, almost 5 times higher), thallium (12 µg/L, 15 times higher), and zinc (14000 µg/L, 116 times higher). As in Quiulacocha, aluminum, iron, and manganese exceeded the cat. 3 EQS, resulting in **3 more exceedances to the national law** (Table 3). Iron, copper, and zinc were also above the normative limit for mining effluents (Table 3).

Although concentrations fluctuate, **historic data reveal stable heavy metal contamination also in Yanamate**. In 2022, we observed nearly the same exceedances of the D.S. N°008-2017-MINAM EQS as in 2024 – i.e., 5 exceedances of cat. 4 and 2 of cat. 3.[12] As the only variation, in 2022, this site had iron concentrations below the cat. 3 EQS (4400 µg/L vs. 5000 µg/L). Conductivity and pH were also above the normative limits in 2022 and 2024.

Tingo River

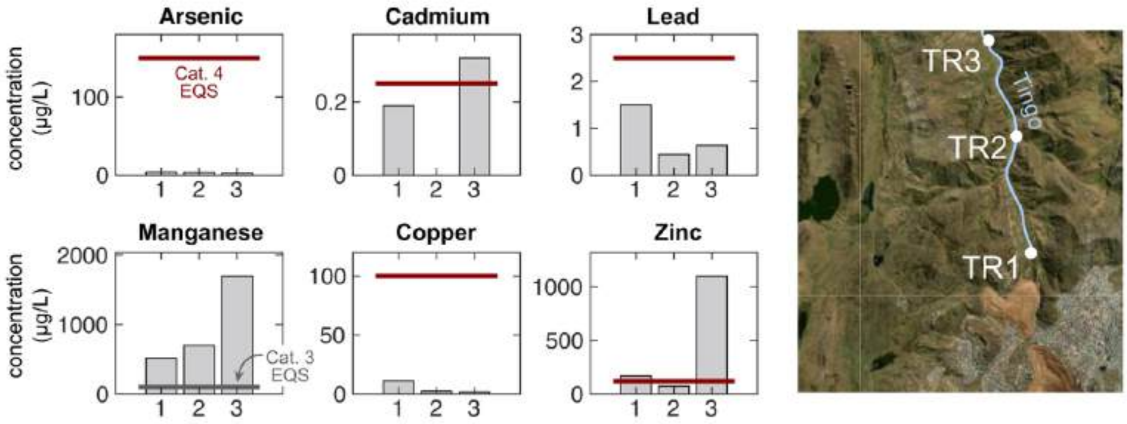

Figure 8. Exceedances in selected heavy metals in the Tingo River watershed. The color code is the same as in Figure 6. Raw data are in Table 3.

In 2024, we observed **3 exceedances of the national EQS for the protection of aquatic ecosystems** in samples collected along the Tingo River – namely, 2 exceedances for zinc at TR1 and TR3, and 1 for cadmium at TR3 (Figure 8 and Table 3). **Manganese was also above the cat. 3 EQS at all sites** (Figure 8), while iron was above the cat. 3 EQS at TR1 and TR2, and above limit for mining effluents at TR2 (Table 3). Several metals consistently decreased from Tingo River's spring (TR1) downstream, suggesting that they leached from under the stockpile (Figure A2). Elements with this behavior include antimony, arsenic, boron, copper, and vanadium. Notably, conductivity followed the same decreasing trend from TR1 to TR3 (Table A2). On the other hand, other metals increased consistently from TR1 to TR3 (e.g., manganese) or only between TR2 and TR3 (e.g., cadmium and zinc; Figure 8), hinting at a secondary pollution source downstream of TR2.

While TR3 was not sampled in the past two campaigns (Table 2), **the other 2 sites showed overall similar water chemistry throughout the years** (Figure A2).[12,13] Zinc always exceeded the cat. 4 EQS at TR1 and, in 2023, was above this value also at TR2. Likewise, manganese was always above the cat. 3 EQS at the two locations. Of the other metals regulated under the D.S. N˚008-2017-MINAM, in 2022, cadmium slightly exceeded the cat. 4 EQS at TR1, while lead showed a constant decrease over time – in 2022, it was above the cat. 4 EQS at both sites; in 2023, it was above the EQS only at TR1; and in 2024, it was below the EQS at both locations (Figure A2).

San Juan River watershed

In this area, we observed **7 exceedances of the national EQS for the protection of aquatic ecosystems** (Figure 9 and Table 3). While all sites exceeded at least twice the cat. 4 EQS for zinc (210

– 540 vs. 120 µg/L), S1 was also slightly above the EQS for cadmium (0.28 vs. 0.25 µg/L), while S2 was above the EQS for both cadmium (1.2 vs. 0.25 µg/L) and thallium (3 vs. 0.8 µg/L). Overall, **S1 and S2 were the most polluted sites**, in agreement with their proximity to mining activities and the Ocroyoc tailing dam (Figure 9 and Figure 3). The exploratory principal component analysis further revealed a subtle difference between S2 and the other samples (Figure A1), which we also noticed in the higher concentration of specific metals – i.e., cadmium, cobalt, manganese, selenium, and thallium. S2 was collected in an effluent of the Ocroyoc tailing dam *before* it joined the Ragra River, which likely explains the slight difference in chemical composition.

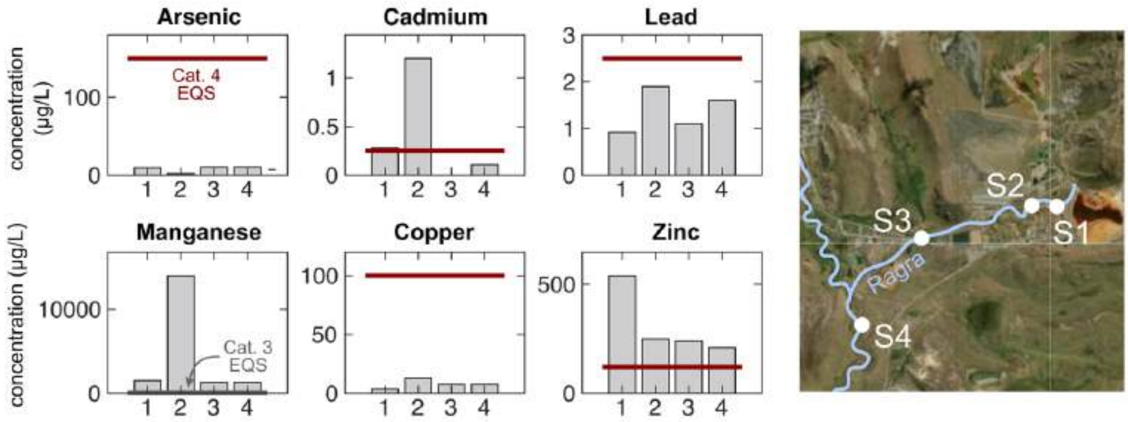

Figure 9. Exceedances of selected heavy metal exceedances in the San Juan River watershed. The color code is the same as in Figure 6. Raw data are in Table 3.

Sites S1 and S3 were also included in the past two campaigns,[12,13] revealing an **overall decrease in pollution throughout the years.** For example, in 2022, S1 had 4 exceedances of the cat. 4 EQS (i.e., cadmium, lead, thallium, and zinc) and 1 in cat. 3 (i.e., manganese); in 2023, we observed 3 exceedances of cat. 4 (i.e., cadmium, thallium, and zinc) and 2 of cat. 3 (i.e., iron and manganese); and in 2024, we had only 2 exceedances of cat. 4 (i.e., cadmium and zinc) and 1 of cat. 3 (i.e., manganese). **Cadmium, zinc, and manganese were consistently the most problematic elements at these sites**, followed by lead and thallium. Conductivity has also been constantly above the cat. 4 EQS at the 2 sites from 2022 until now.

Tap waters

For tap waters, we observed only one minor exceedance of the D.S. 031-2010-MINSA – i.e., for iron at Pargasha (310 µg/L vs. 300 µg/L; Table 3). While specific concentrations of heavy metals may vary, these results confirm past findings from 2022[12] and 2023[13] of an **overall acceptable drinking water quality in Cerro de Pasco.**

Key findings

Surface waters

In this latest investigation, we confirmed **widespread surface water contamination in Cerro de Pasco and surrounded areas linked to local mining activities**. Overall, we recorded **32 exceedances of the national Environmental Quality Standard for cat. 4 waters**, 25 for cat. 3 subgroup D1, and 22 for cat. 3 subgroup D2 (as defined in D.S. 004-2017-MINAM[14]; Table 4). We also recorded **10 exceedances of the Maximum Permissible Limits of the mining effluents normative** (D.S. 010-2010-MINAM[16]), which primarily occurred in Lake Quiulacocha and Lake Yanamate (Table 4). Across all sites and years (2022 – 2024), **conductivity, cadmium, and zinc** were the parameters most frequently exceeding the cat. 4 EQS, while **manganese**, which is not regulated in category 4, showed the greatest number of exceedances of the cat. 3 EQS. Other metals that consistently – though not always – surpassed the cat. 4 EQS included **lead and thallium**. In the last three years, arsenic, copper, iron, and pH were outside regulatory standards only in the lakes.

These results are broadly consistent with past sampling campaigns,[12,13] which also documented severe surface water contamination in the lakes (Q1 and Y1) and in areas immediately surrounding the mine and its activities (TR1, S1, S2, and S3). Although with some fluctuations and exceptions,

Table 4. Overview of exceedances in surface water samples. Exceedances to cat. 4 EQS, cat. 3 EQS, and the Maximum Permittable Limits (MPL) from mining effluents. This calculation also includes exceedances in conductivity and pH values. The last column on the right summarizes the parameters with most exceedances (of cat. 4 EQS) since 2022; values highlighted in grey are common across all areas.

ID	Exceedances to cat. 4 EQS	Exceedances to cat. 3 EQS	Exceedances to MPL mining	Parameters with most the exceedances since 2022
TR1	2	1	0	Conductivity, cadmium, manganese, zinc (+ lead)
TR2	1	1	1	
TR3	2	1	0	
Q1	9	10	6	Conductivity, pH, arsenic, aluminum, cadmium, copper, iron, manganese, nickel, zinc (+ lead, selenium, thallium)
S1	3	1	0	Conductivity, cadmium, manganese, zinc (+ thallium, lead)
S2	4	1	0	
S3	2	1	0	
S4	2	1	0	
Y1	7	8 (group D1) 5 (group D2)	3	Conductivity, pH, aluminum, cadmium, copper, iron, manganese, thallium, zinc
Tot	**32**	**25** (group D1) **22** (group D2)	**10**	

heavy metal concentrations across the study area have shown a gradual decline over the years.[5,12,13] While the overall order-of-magnitude of the contamination remains constant, this subtle downward trend may reflect changes in climatic conditions – e.g., variations in seasonal rainfall and associated dilution effects – and/or being the result of ongoing remediation efforts of the Excelsior stockpile.[21] Nevertheless, **given the scale of the contamination and the well-documented health impacts,**[5,8] **urgent remediation remains a critical priority.**

Tap waters

In terms of heavy metals, tap water quality was overall acceptable, with only a single minor exceedance in Paraghsa (P1; Table 3). This exceedance referred to iron, a parameter describing water's organoleptic quality rather than safeness for human consumption.[15] **These findings are consistent with the previous two campaigns**, which reported no exceedances of D.S. 031-2010-MINSA.[12,13]

While tap water currently presents a lower contamination risk than surface waters, improvements in water treatment are recommended to ensure safe domestic consumption and prevent chronic exposure, particularly for vulnerable populations.

Implications for human health and the environment

These findings add to the growing body of evidence demonstrating the high potential for chronic heavy metal exposure in the population of Cerro de Pasco – which sits in one of the most high-risk regions for mining-related pollution exposure.[22]

Most of the substances repeatedly detected above normative limits in the last 3 years are well-known toxicants listed among priority pollutants worldwide. Indeed, **the World Health Organization classifies cadmium and lead among the chemicals of major public health concern**.[20] Arsenic and mercury, other heavy metals in this list,[20] had also concerning levels in specific sampling sites and/or other environmental matrices – e.g., soil.[12] Cadmium is associated with kidney damage, bone demineralization, respiratory issues, and has been classified as a Class I carcinogen by the International Agency for Research on Cancer.[23] Lead, a cumulative toxicant, affects multiple body systems, including the neurological, hematological, gastrointestinal, cardiovascular, and renal systems.[24] Inorganic lead is also a probable carcinogen (Class 2A).[25] **Several epidemiological studies reported elevated levels of lead in the blood and high levels of cadmium, arsenic, and mercury in the urine in Cerro de Pasco residents** (reviewed in our 2019 report[5]). Supporting these findings, we repeatedly observed high concentrations of these same metals in hair samples of the Cerro de Pasco infant population.[5,8] This data underscore a **clear link between environmental contamination and exposure**. While overall less problematic – they are essential elements – also zinc and manganese can cause health problems if chronically present in high concentrations.[26,27] Furthermore, the co-occurrence of multiple metals in high concentrations adds to an already critical situation, further raising the potential for synergistic adverse effects.

These metals also pose risks to the ecosystem. While restoring the once-natural lakes around Cerro de Pasco may not be feasible in the short term, **downstream environments remain highly vulnerable**. For example, the San Juan River drains into Lake Junín, a Ramsar site since 1997 and an area of national ecological and agricultural importance.[28,29] This high-altitude wetland supports rare and endemic species, including the Junin Grebe and Junin Rail – both classified as endangered in the IUCN Red List of Threatened Species[30,31] – and provides critical ecosystem services such as water purification, carbon storage, and pasture for local communities.[29] A 2014 study showed a clear link between the construction of the Upamayo hydroelectric dam in 1932 and the subsequent accumulation of lead and zinc in the lake's sediments to levels that exceed the EPA environmental standard by one order of magnitude.[32] Built to supply electricity to Cerro de Pasco's mining industry, the dam diverted the San Juan River, thus channeling polluted sediments into Lake Junín and placing its fragile ecosystem under long-term threat.[32] These findings underscore the far-reaching ecological consequences of mining activities and highlight the urgent need for environmental protection and sustainable watershed management even beyond the Simón Bolívar district borders.

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Appendix

Table A1. Overview of the analytical methods' limit of detection and relative error for the 21 heavy metals (values provided by the laboratory). When not available (n.a.), analytes were either always > their limits of detection.

	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Cobalt	Chromium	Iron	Manganese	Mercury	Molybdenum	Nickel	Lead	Copper	Selenium	Tin	Thallium	Vanadium	Zinc
Limit of detection (µg/L)	25	n.a.	n.a.	n.a.	0.1	n.a.	0.1	1	5	n.a.	n.a.	0.5	1	n.a.	1	n.a.	1	1	0.1	1	n.a.
Average relative error (%)	26%	n.a.	29%	30%	24%	26%	29%	25%	23%	24%	24%	n.a.	n.a.	21%	29%	25%	n.a.	n.a.	26%	n.a.	27%

Table A2. Overview of samples' location and general water chemistry parameters. The cells highlighted in red exceed the cat. 4 Environmental Quality Standards (EQS) for Peru.

ID	Sample type	Location	Latitude	Longitude	pH	Conductivity (µS/cm)	Temperature (°C)
RT1	stream water	Tingo River	-10.65423	-76.26281	8.31	**2068**	12.6
RT2	stream water	Tingo River	-10.63661	-76.26505	8.21	**1061**	11.2
RT3	stream water	Tingo River	-10.62211	-76.26932	8.44	747	10.3
Q1	lake water	Lake Quiulacocha	-10.70278	-76.28539	**2.37**	**13150**	21.8
S1	stream water	San Juan River	-10.69961	-76.28828	7.98	**1181**	13.1
S2	stream water	San Juan River	-10.69950	-76.29122	7.77	**2391**	15.7
S3	stream water	San Juan River	-10.70329	-76.30414	8.33	**1411**	13.0
S4	stream water	San Juan River	-10.71329	-76.31111	8.19	**1252**	13.8
Y1	lake water	Lake Yanamate	-10.72000	-76.25128	**2.55**	**2740**	12.3
P1	tap water	Paragsha	-10.67383	-76.26756	6.60	286	6.7
SJ1	tap water	Hotel Señorial	-10.66660	-76.25263	7.60	154	11.0
			Cat. 4 EQS		6.5 – 9	1000	
			Cat. 3 EQS		6.5 – 8.5	2500	
			Mining effluents		6 – 9		
			Human use		6.5 – 8.5	1500	

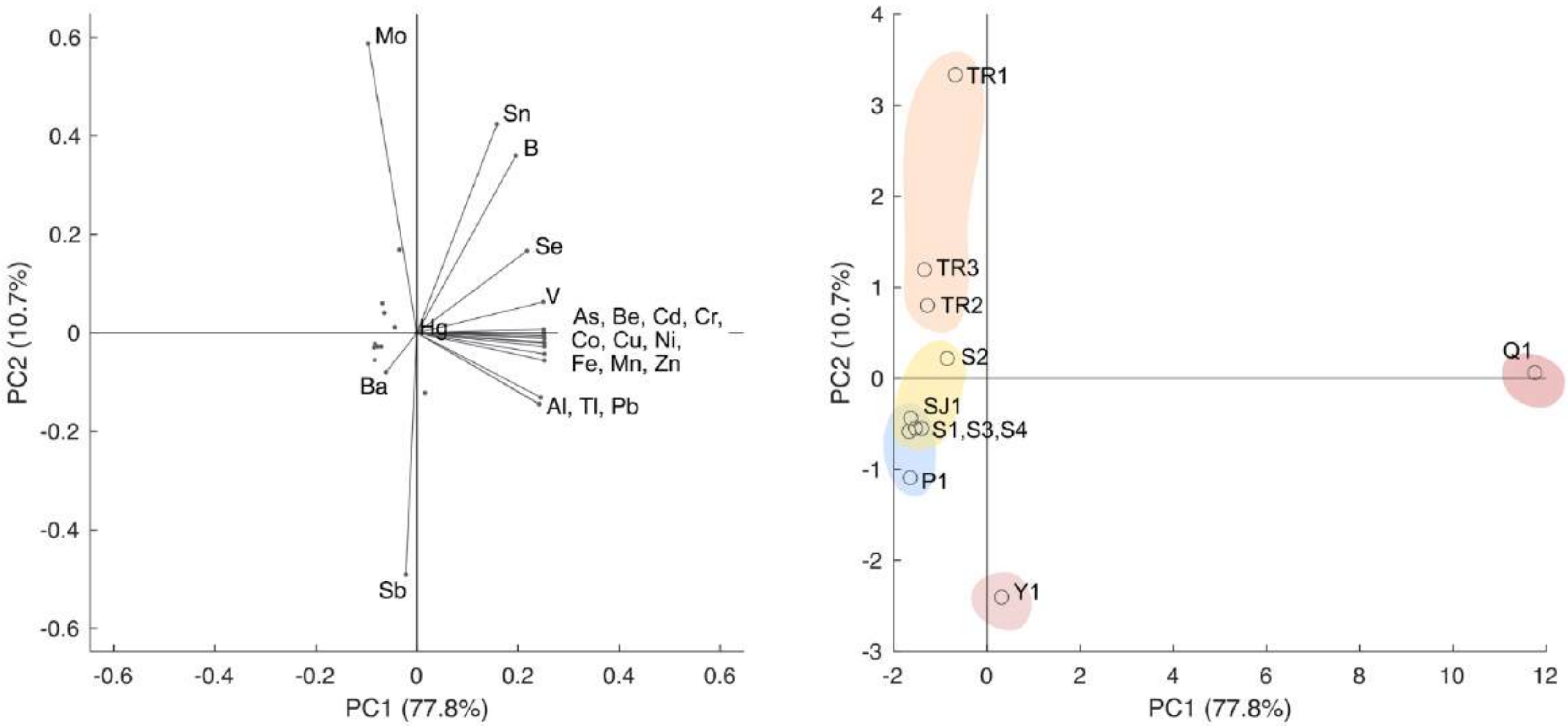

Figure A1. Exploratory principal component analysis (biplot on the left, scores on the right). The first two principal components (PC) explained 88.5% of the variance. Q1 and Y1 were the most diverse samples within the dataset (red areas on the right graph). Samples collected along the Tingo River (orange area; TR1 to TR3) gathered in the VI quadrant, while those taken along the Ragra River and San Juan River (yellow area; S1 to S4) were overall similar among themselves and to tap waters (blue areas).

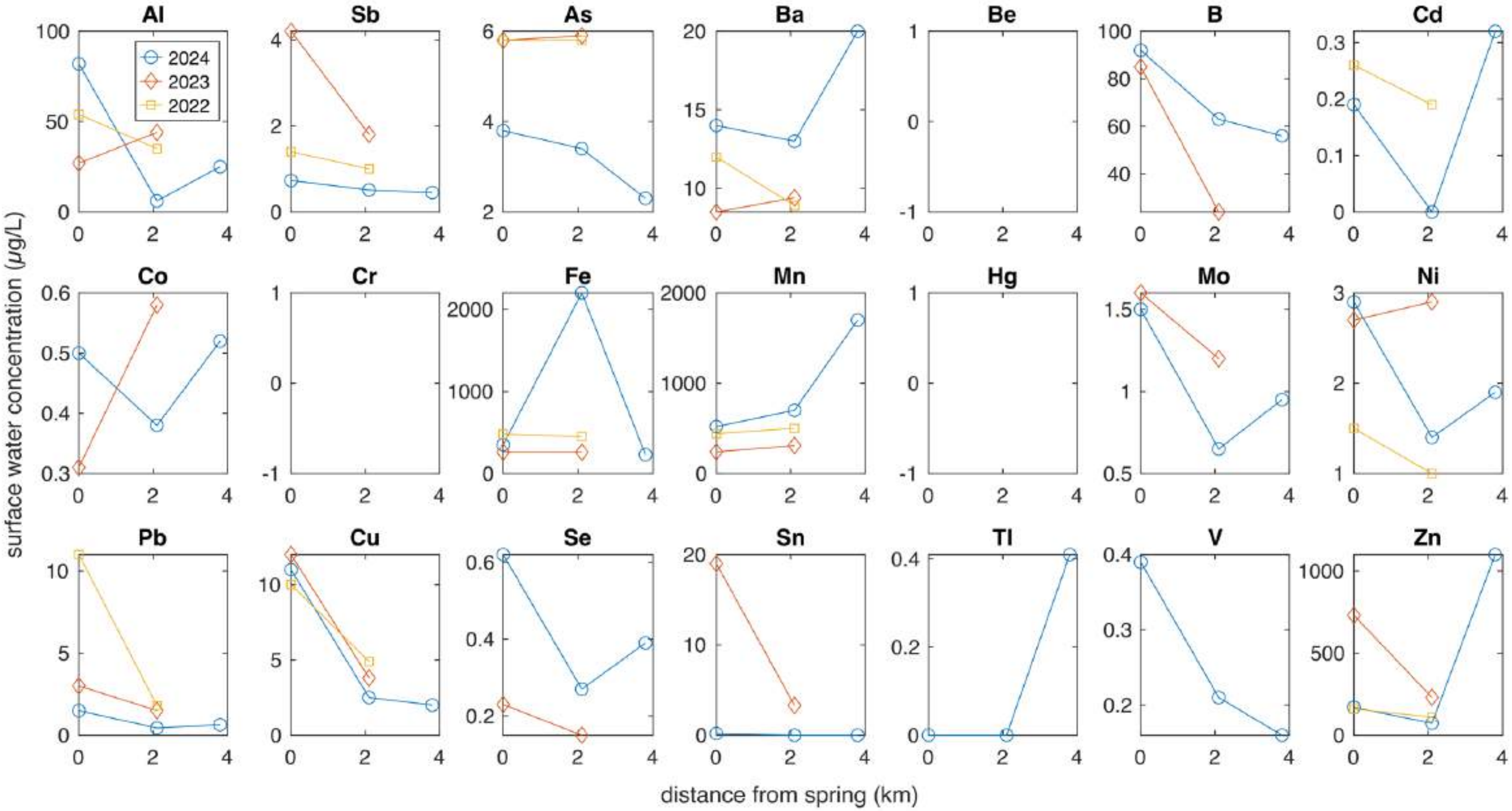

Figure A2. Changes in the concentration of dissolved heavy metals along the Tingo River from 2022 to 2024. Distances from the spring are estimated using the measuring tool in Google myMaps. Previous year data are taken from the Reports of the 2022[12] and 2023[13] sampling campaigns. Beryllium, mercury, and chromium were never detected.