Supplementary Section

Experimental heavy metal removal trials combined the analytical capabilities of two institutions. The control physicochemical characterization (pH, turbidity, electrical conductivity and temperature) was carried out in the Process Laboratory of the Pedro Ruiz Gallo National University, using calibrated direct measurement equipment. On the other hand, the spectrometric quantification of trace metals (Arsenic and accompanying metals) before and after contact with the residual biomass of sugarcane bagasse, was delegated to the Regional Water Laboratory of Cajamarca under accredited protocols NTP-ISO/IEC 17025, guaranteeing the traceability and sensitivity required for water matrices for human consumption.

Annex A: Analytical Quality Assurance (Regional Water Laboratory - Cajamarca)

A.1 Operational Protocol and Regulatory Framework

The control, monitoring and assurance of analytical quality for the instrumental quantification of heavy metals in drinking water samples (evaluated before and after the biosorption process with residual biomass of sugarcane bagasse) were strictly governed by the guidelines of the international standard NTP-ISO/IEC 17025. The tests were carried out using inductively coupled plasma optical emission spectrometry (ICP-OES) and atomic absorption spectrometry, using internationally standardized methods (Standard Methods/EPA).

The robustness and scientific validity of the reported data rest on a system of direct metrological traceability to the standards of the International System of Units (SI), guaranteed through the continuous use of Certified Reference Materials (MRC) and the annual external calibration of the volumetric and analytical infrastructure by laboratories accredited by the National Institute of Quality (INACAL).

A.2 Internal Quality Control Components (Per Test Lot)

To ensure accuracy, precision and the absence of interference or cross-contamination during the reading of the experimental samples, each test lot integrated the following mandatory analytical controls:

- **Method Target (BK):** Prepared with ultrapure water (Type I reagent grade) and subjected to the same nitric acid digestion (HNO_3) procedure as real samples. Its function is to analytically demonstrate the cleanliness of the instrumental system, reagents and glassware.
- **Fortification Targets (BFL 1 and BFL 2):** Analytical target matrices intentionally added with known and certified concentrations of the metal under study. They are used to assess the resilience of the system and quantify any loss or bias during the pre-read stages.
- **Intermediate Verification Solution (IPCI):** An analytical control standard independent of the calibration curve that is read interleaved between sample batches. Its purpose is to immediately monitor and correct instrumental drift (deviations in the stability of the optical signal or plasma torch) throughout the working day.

A.3 Validation Criteria for Acceptance of Results

The concentration data obtained in the adsorption tests were considered statistically valid and free of bias only after meeting the following laboratory operational tolerances:

1. **No Contamination Criterion:** The concentration of the analyte in the Method Target (BK) must have been strictly below the Method Detection Limit (LDM). Any reading above this threshold triggered automatic batch rejection and repeat digestion.
2. **Accuracy Criterion (Recovery):** The recovery percentage calculated for Fortification Targets (%BFL) and continuous control solutions (%IPCI) had to fit rigorously within the range of 85% to 115%. This certifies that the analytical environment does not underestimate or overestimate the actual concentration of metals.
3. **Linearity Criterion:** The multipoint calibration curve active during batch processing should have presented a linear correlation coefficient ($R^2 \geq 0.995$).

Annex B: Instrument Calibration

Instrumental Analysis: Optical Emission/Absorption Spectrometry
Analytical Element/Line: Arsenic (As 193.759 nm) — Channel 474
Calibration Date: 07/19/2022 10:31:07
Origin Laboratory: Cajamarca Regional Water Laboratory

B.1 Fundamentals of Spectrometric Calibration

For the quantitative determination of traces of Arsenic (As) in samples of water for human consumption treated with the residual biomass of sugarcane bagasse, the optical standardization of the spectrometer was carried out using the specific emission line of 193.759 nm (Channel 474). This procedure ensures maximum analytical sensitivity and minimizes concurrent spectral interference in the water matrix. The official timestamp of the procedure was recorded on 19/07/2022 at 10:31:07 h.

The mathematical adjustment used for the construction of the instrumental response function corresponded to a Linear Regression model with inverse concentration weighting (1/Conc), which optimizes the precision at the lower end of the curve (low concentrations).

B.2 Multipoint Calibration Curve Data Matrix

The detector response was evaluated by an analytical design of five independent calibration points (C_1 to C_5), prepared from a Certified Primary Standard with NIST traceability. The theoretical values against the experimental responses of the team are detailed below:

- **Standard 1 (C_1):** Established Concentration: 0.05000 ppm | Concentration Found: 0.04888 ppm | Absolute Deviation (Diff): -0.00112 ppm.
- **Standard 2 (C_2):** Established Concentration: 0.02500 ppm | Concentration Found: 0.02541 ppm | Absolute Deviation (Diff): +0.00041 ppm.
- **Standard 3 (C_3):** Established Concentration: 0.10000 ppm | Concentration Found: 0.10198 ppm | Absolute Deviation (Diff): +0.00198 ppm.
- **Standard 4 (C_4):** Established Concentration: 0.25000 ppm | Concentration Found: 0.24795 ppm | Absolute Deviation (Diff): -0.00205 ppm.
- **Standard 5 (C_5):** Established Concentration: 0.50000 ppm | Concentration Found: 0.49777 ppm | Absolute Deviation (Diff): -0.00223 ppm.

B.3 Quality and Linear Conformity Parameters

According to the calculation algorithm of the instrumental software of the Regional Water Laboratory of Cajamarca, the equation of the generated line exhibited the following control parameters:

- **Correlation Coefficient (R):** 0.999902 (R^2 = 0.999804). This value easily exceeds the analytical acceptance criterion stipulated by the **NTP-ISO/IEC 17025** standard ($R^2 \geq 0.995$), confirming an excellent mathematical proportionality between the signal strength and the metal concentration.

- **Method Detection Limit (MDL):** 0.004060 ppm (4.06 µg/L), an ideal threshold to track arsenic concentrations significantly below the Maximum Permissible Limit for drinking water established by Peruvian legislation (0.01 mg/L).
- **Method Quantification Limit (MQL):** 0.013532 ppm (13.53 µg/L).
- **Standard Estimate Error:** 0.064129.

Table S1 Calibration Curve Regression Data Matrix.

Patron Name	Established Concentration (ppm)	Concentration Found (ppm)	Absolute Difference (Diff)	Percentage difference (%)	Analytical Signal (S)IR
C_1	0.00500	0.00488	0.000	-2.36	4.6691
C_2	0.02500	0.02541	0.000	1.65	2.5351
C_3	0.10000	0.10198	0.002	1.98	10.248
C_4	0.25000	0.24795	-0.002	-8.19	24.952
C_5	0.50000	0.49777	-0.002	-4.53	4.9890

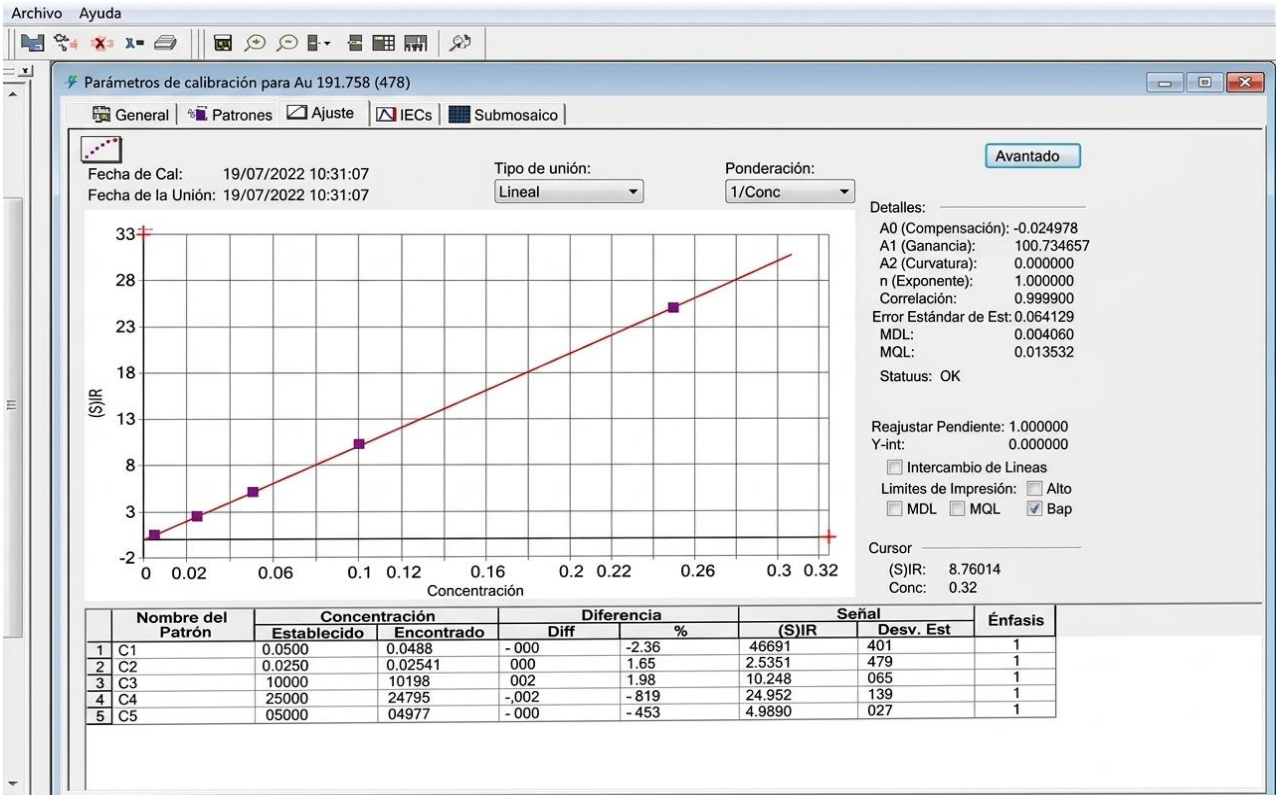

Figure S1 Analytical calibration curve of signal intensity versus concentration for Arsenic (As 193.759 nm) by spectrometry. Analytical control values: Correlation coefficient R = 0.999902; Standard Estimation Error = 0.064129; Method Detection Limit (MDL) = 0.004060 ppm; Method Quantization Limit (MQL) = 0.013532 ppm.

Annex C: Fundamentals And Operational Control Matrix in Biosorption

Physicochemical Analysis - UNPRG Process Laboratory.

C.1 Fundamentals

The characterization and monitoring of the physicochemical variables of drinking water were carried out in the Process Laboratory of the Pedro Ruiz Gallo National University (UNPRG). The control of these parameters is essential in water remediation processes, since variables such as pH, electrical conductivity and temperature determine the surface charge of the residual biomass of sugarcane bagasse (Saccharum officinarum), the chemical speciation of heavy metals in solution and the kinetics of mass transfer to the active adsorption sites.

C.2 Test and Instrumentation Protocol

The analyses were carried out immediately before (baseline) and after contact with the sugarcane bagasse adsorbent bed, using standard direct reading methods according to the laboratory's technical specifications:

- **Hydrogen Potential (pH):** Measured by a multi-parameter digital potentiometer calibrated with buffer solutions (Certified Reference Substances) at pH 4.01, 7.00 and 10.01. Strict pH control ensures the stability of the functional groups (cellulose, hemicellulose and lignin) of the biomass.
- **Electrical Conductivity:** Determined with a digital conductivity meter automatically compensated by temperature, expressed in microsiemens per centimeter (µS/cm). It allows monitoring of the variation in the total concentration of dissolved ions after treatment.
- **Turbidity:** Evaluated by means of an analytical turbidity meter calibrated with formazine standards, recording the values in Nephelometric Turbidity Units (NETs) to rule out the detachment of microparticles or fine organic matter from the bagasse itself.
- **Temperature:** Recorded in situ using integrated thermistor sensors to ensure the reproducibility of thermal tests and correct for ion solubility variations.

C.3 Process Quality Assurance Criteria (UNPRG)

The experimental readings at the UNPRG complied with the following internal control guidelines:

1. **Drift Verification:** Calibration and verification of the electrodes at the beginning and end of each filtration block.
2. **Triplicate Analysis:** Each physicochemical sample was processed in triplicate to determine the standard deviation and ensure that the experimental coefficient of variation was strictly less than 5%.

Table S2 Physicochemical analysis of water quality of the Morrope well water sample.

Parameter analyzed	Unit of Measurement	Value obtained
Odor	---	Acceptable
Taste	---	Acceptable
Color	Pt Scale	50
Turbidity	NTU	0.7
pH	pH value	7.58
Conductivity (25°C)	µmho/cm	1416
Total solids	mg/L	707
Hardness	mg $CaCO_3$/L	850
Sulfates	mg SO_4^{-2}/L	360

Source: Annex Water Quality Analysis Report No. 06.