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Rapid Determination of Lead(II) and Cadmium(II) Ions in Water Using Paper-Based Colorimetric Sensors

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Abstract. This methodological article proposes a two-zone paper platform for rapid Pb(II) and Cd(II) determination in water. Rhodizonate-cellulose and dithizone-DTAB-silica zones are combined with controlled imaging, calibration and quality control. Twelve peer-reviewed sources from 2023-2026 guide the design. With no original measurements, performance characteristics remain validation requirements. The platform is intended for analytical-chemistry education and preliminary screening; threshold-level results require confirmation by a reference method.

Keywords: *Pb(II); Cd(II); paper sensor; colorimetry; water analysis.*

1. Introduction

Lead and cadmium enter water through mining, metal processing, batteries, pigments, fertilizers, electronic waste and corroding infrastructure. Their persistence and toxicity make rapid screening important, although authoritative measurement usually relies on atomic spectrometry. Paper devices bridge sampling and laboratory confirmation through capillary transport, low reagent volume and visible response. Recent reviews identify affordability, portability and multiplexing as major advantages [1,3]. Rigorous control is still necessary: cellulose porosity, background colour, humidity, reagent distribution and camera processing can change the signal. The present work therefore treats paper, recognition chemistry, sample, illumination and calibration as one analytical system. Its objective is an original methodology for separate Pb(II) and Cd(II) zones, not unperformed experiments.

2. Recent evidence and analytical gap

Work from 2023-2026 shows rapid development of portable heavy-metal sensors. A microfluidic paper device combined

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Pb(II)/Cd(II) electrochemistry with an RGB zone [2]. Cellulose-trapped lead-rhodizonate enabled device-free Pb(II) screening [4], while dye-impregnated paper produced visible responses [6]. Cd(II) has been measured through dithizone-surfactant-silica colour [5], dipsticks [7], selective chemosensors [8] and smartphone assays [10]. Quantum-dot Pb(II) sensing [9], multi-metal strips [11] and machine-learning interpretation [12] further expand field readout. Yet solution limits cannot be transferred automatically to paper, single-ion tests do not reproduce natural matrices, and automatic camera settings alter colour. The proposed design uses isolated zones, one image reference and explicit acceptance criteria.

3. Colorimetric measurement principle

Metal coordination changes the spectrum of a chromophore; on paper, scattering and capillary transport also affect the observed colour. The signal depends on complex concentration, deposited reagent mass, wet area, drying history and illumination. Digital images provide RGB or CIELAB values, but the response channel must be selected during method development. If I0 is the mean channel intensity of the reagent blank and I is the value after reaction, an absorbance-like response is:

$$A_{channel} = \log_{10}(I_0 / I)$$

A calibration model is accepted only when the response is monotonic, unsaturated and free of structured residuals. An internal white/grey reference captured in the same frame reveals illumination or exposure drift. CIELAB colour difference may support the primary channel, but unknown samples must be processed by the same predefined algorithm [3,10,11].

4. Lead(II) recognition zone

Rhodizonate is selected for the Pb(II) zone because lead forms a strongly coloured complex with oxygen-donor sites. Cellulose can kinetically retain the product and reduce uncontrolled bulk precipitation. A recent microdrop study reported an approximately 1 mg L-1 visual and quantitative limit with extensive ion comparison [4]. This supports screening but does not establish compliance-level sensitivity for every water matrix. The proposed zone therefore pairs rhodizonate-treated cellulose with an untreated optical blank

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from the same paper lot. Reagent loading, pH, applied volume, drying conditions and reading time are optimized together. Alternative EBT and BTB paper systems have reported limits of 18 and 6 mg L–1 [6], indicating suitability mainly for higher contamination. Values outside the validated range are diluted or reported qualitatively; they are never estimated by extrapolating the calibration.

5. Cadmium(II) recognition zone

Cadmium is difficult to distinguish because many sulfur- and nitrogen-donor ligands also bind Pb(II), Hg(II), Zn(II) and Cu(II). Dithizone selectivity depends strongly on acidity and ligand environment. A silica-sol system modified with DTAB and dithizone produced an immediate purple-to-orange Cd(II) response, a 0.01–0.25 mg L–1 range and a reported 5.0 µg L–1 solution limit [5]. The proposed Cd(II) zone immobilizes this formulation as a reproducible thin layer, but its paper performance must be validated independently. Recent dithizone dipsticks reported 0.10 mg L–1 for Cd(II) with a response within 60 s [7]; a newer paper chemosensor reported visual and instrumental limits of 0.23 and 0.13 µM [8]. These differences show that immobilization controls sensitivity. Pb(II), Zn(II), Cu(II), Hg(II), Fe(III), Ca(II) and Mg(II) must be tested individually and in mixtures.

6. Device design and recent performance

The laminated card contains separate circular Pb(II) and Cd(II) zones plus a neutral reference patch. Hydrophobic boundaries restrict spreading; identical sample volumes are applied to each zone. Paper conditioning, deposition volume, dark drying, sealed storage, lot number and control-card response are documented. Spatial separation permits different chemical conditions and limits cross-talk.

Table 1

Selected recent systems; study designs and units are not directly interchangeable

System	Ion	Reported limit	Analytical lesson
Rhodizonate paper [4]	Pb	≈1 mg L–1	Simple visual screening
DZ–DTAB–silica [5]	Cd	5.0 µg L–1	Paper needs revalidation
EBT/BTB paper [6]	Pb	18/6 mg L–1	Higher-level screening
Dithizone strips [7]	Pb/Cd	1.26/0.10 mg L–1	Response ≤150/60 s

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7. Author-designed analytical scheme

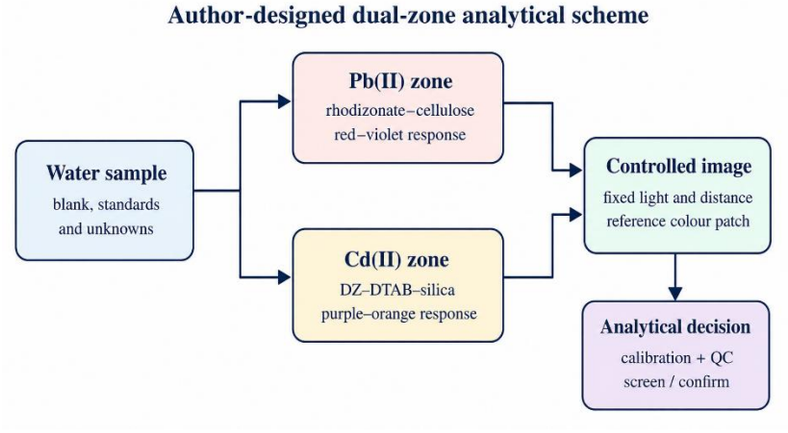

Figure 1

Dual-zone Pb(II)/Cd(II) workflow. Source: designed by the author

One water aliquot is split between the zones. Both reactions and the reference patch are photographed in one controlled frame. Accepted images are blank-corrected, evaluated against separate calibration functions and assigned as below, within or above the validated range.

8. Proposed procedure and digital readout

Materials include cellulose paper, hydrophobic laminate, sodium rhodizonate, dithizone, DTAB, colloidal silica, buffers, certified Pb(II)/Cd(II) standards, calibrated pipettes and a matte LED imaging enclosure. At least one blank and six standards per ion bracket the intended screening interval. Equal volumes are applied; reaction time is fixed separately for each zone. Calibration levels use independently fabricated cards. Images are acquired at constant distance and angle with flash, filters and automatic enhancement disabled. Focus, exposure and white balance are locked when possible. Mean RGB, CIELAB coordinates and spot uniformity are extracted from a fixed central region. Duplicates, an unspiked matrix and fortified samples accompany unknowns. Digital models are kept transparent unless multi-day, multi-device data justify machine learning [9–12]. Metal-containing cards and solutions are collected as hazardous waste.

9. Validation, selectivity and quality control

Validation covers range, residual linearity, reporting limit, precision, recovery, shelf stability, dilution integrity and reference-method agreement. A high R^2 alone is insufficient. Starting targets are 80–120% recovery, relative

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standard deviation ≤15% near the reporting limit and ≤10% at higher levels. Selectivity is challenged with common metal ions, major anions and varied hardness, pH, organic matter, turbidity and colour. Mixtures are essential because competitive binding differs from single-ion tests. Cards are rejected when blank colour, reference-patch values, spot uniformity or mid-range control exceeds limits. Representative samples are compared with AAS or ICP measurement, and threshold-level positives are confirmed. Filtration or digestion changes the measurand and must be reported.

10. Discussion and limitations

The proposed architecture combines distinct recognition zones with one imaging and quality-control system. It is rapid, uses little sample and links coordination chemistry, capillary transport, calibration and uncertainty. It may triage field samples before laboratory analysis. Its main limitation is the absence of original data: sensitivity, shelf life, cross-reactivity and accuracy remain to be tested. Paper lot, humidity, automatic phone processing and coloured matrices may dominate uncertainty. Implementation should optimize each zone, establish image-control limits, validate the combined card in several matrices, compare it with a reference technique and then perform a blinded field study. Recent digital and machine-learning approaches are promising [9–12], but cannot replace representative calibration, raw-data retention or confirmation.

11. Conclusion

A defensible rapid paper assay for Pb(II) and Cd(II) requires controlled chemistry, paper fabrication, imaging and validation. The proposed rhodizonate-cellulose and DZ-DTAB-silica zones provide complementary recognition, while an internal reference and predefined quality rules protect interpretation. The framework is suitable for analytical-chemistry education and screening research. It should be submitted as a methodological article unless experimentally verified results are later added.

Ethics and data availability

Not applicable. This methodological study did not involve human participants or animals and did not generate original experimental or field-sample data.

References:

[1] Fakayode, S. O., Walgama, C., Fernand Narcisse, V. E., & Grant, C. (2023). Electrochemical and colorimetric nanosensors for detection

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of heavy metal ions: A review. Sensors, 23(22), 9080. https://doi.org/10.3390/s23229080

[2] Hermansyah, A., Rees, N. V., Gunlazuardi, J., & Wibowo, R. (2023). Development of microfluidic paper-based analytical devices (μPADs) for determination of Cd2+, Pb2+, and Cu2+ ions in mineral water. Jurnal Kimia Sains dan Aplikasi, 26(9), 353-362. https://doi.org/10.14710/jksa.26.9.353-362

[3] Malik, S., Singh, J., Saini, K., Chaudhary, V., Umar, A., Ibrahim, A. A., Akbar, S., & Baskoutas, S. (2024). Paper-based sensors: Affordable, versatile, and emerging analyte detection platforms. Analytical Methods, 16(18), 2777-2809. https://doi.org/10.1039/D3AY02258G

[4] Sultana, K. A., Hernandez, J., Sheets, S., et al. (2024). Device-free colorimetric sensing of lead in water by kinetically trapping lead(II) rhodizonate into a solid-solution of cellulose paper. Sensing and Imaging, 25, 61. https://doi.org/10.1007/s11220-024-00482-5

[5] Litluechai, A., Prompa, A., Uppachai, P., et al. (2024). Highly sensitive colorimetric detection of Cd(II) based on silica sol modified with dithizone and cationic surfactant. RSC Advances, 14, 32101-32108. https://doi.org/10.1039/D4RA03983A

[6] Poovadichalil, N. M., Ullah, A., Maurya, M. R., et al. (2025). Eco-friendly paper-based colorimetric sensor for portable and rapid detection of lead (II) ions in aqueous environment. International Journal of Environmental Science and Technology, 22, 15467-15478. https://doi.org/10.1007/s13762-025-06636-6

[7] Solhtalab, M., Majdinasab, M., Zarei, S., & Majdinasab, E. (2025). Development of a simple and rapid paper-based dipstick test strip for the colorimetric detection of lead and cadmium in water. Journal of Hazardous Materials Advances, 19, 100867. https://doi.org/10.1016/j.hazadv.2025.100867

[8] Mousavi, S. H., Mohammadi, A., Zanjanchi, M. A., & Fallah Moafi, H. (2025). Paper-based colorimetric chemosensor for highly sensitive and selective detection of Cd2+ in water and food samples. Analytical Methods, 17(46), 9365-9380. https://doi.org/10.1039/D5AY01326G

[9] Azizi, N., Hallaj, T., Majidinia, M., Samadi, N., & Azizzadeh, B. (2025). WS2 QDs based dual fluorometric and paper based colorimetric sensor for Pb2+ assay in water and food samples. Journal of Food Composition and Analysis, 139, 107097. https://doi.org/10.1016/j.jfca.2024.107097

[10] Tandey, K., Shrivas, K., Patel, A. K., et al. (2025). Smartphone-based colorimetric sensing of cadmium in milk for food safety monitoring. Journal of Food Composition and Analysis, 148(3), 108365. https://doi.org/10.1016/j.jfca.2025.108365

[11] Malik, S., Singh, J., Umar, A., et al. (2026). Smartphone-integrated paper sensor strips for rapid and on-site detection of heavy metal ions in environmental water samples. Journal of Photochemistry and Photobiology A: Chemistry, 471, 116675. https://doi.org/10.1016/j.jphotochem.2025.116675

[12] Kahmei, R., et al. (2026). Paper-based colorimetric sensor using L-cysteine-functionalized silver nanoparticles: Integrating DFT insights and machine learning for cadmium detection in water. Environ. Nanotechnol. Monit. Manag., 26, 101174. https://doi.org/10.1016/j.enmm.2026.101174