Supplementary Material S1: Detailed Scoring Criteria and Study Evaluation

Each study from Section 3 was evaluated across several key aspects to systematically compare the performance and suitability of different colourimetric sensor technologies for heavy metal detection in freshwater. A score colour code was assigned for each variable according to the following criteria:

1. Analytical Performances

- Sensitivity / Limit of Detection (LoD):
  • Orange (lowest): LoD values in the ppm range, insufficient for detecting trace heavy metals.
  • Yellow (average): LoD values approaching the ppb range, but with some limitations in consistency or reliability.
  • Green (highest): Excellent sensitivity with LoD in the low ppb range, ensuring reliable trace detection.
- Selectivity / interferences:
  • Orange: Significant interference from non-target ions with little to no mitigation strategies reported.
  • Yellow: Moderate interference addressed by partial optimization of the sensor design.
  • Green: High selectivity with robust interference mitigation, ensuring accurate detection even in complex matrices.

2. Applicability

- Response Time:
  • Orange: Response times exceeding 2 hours, which are impractical for real-time monitoring.
  • Yellow: Response times between 10 minutes and 1 hour, adequate for many applications but not optimal.
  • Green: Rapid response (<10 minutes) suitable for on-site and real-time monitoring scenarios.
- Working pH Range:
  • Orange: The sensor operates outside the typical freshwater pH range (6–8) or no pH information is provided.
  • Yellow: The sensor functions within a partially overlapping pH range with freshwater

environments.

• Green: The sensor performs optimally within the standard freshwater pH range (6–8).

- Stability and Shelf-life:

  • Orange: Short-term stability (e.g., less than 7 days) or requires strict storage conditions.

  • Yellow: Moderate stability (7–40 days) under controlled conditions.

  • Green: Long-term stability (40–90 days) under room temperature or minimal storage requirements.

3. Safety and Environmental Impact

- Chromophore Type:

  • Orange: Use of synthetic chromophores known to be toxic or environmentally hazardous.

  • Yellow: A mix of synthetic and natural chromophores, with some environmental concerns remaining.

  • Green: Use of natural chromophores that are non-toxic and environmentally benign.

- Membrane Composition:

  • Orange: Predominantly synthetic materials with low biodegradability.

  • Yellow: A combination of bio-based and synthetic materials, offering moderate sustainability.

  • Green: Fully bio-based membranes with high biodegradability and minimal environmental impact.

- Immobilization Technique:

  • Orange: Reliance on toxic cross-linking agents (e.g., aldehydes) that pose user and environmental risks.

  • Yellow: Use of chemical immobilization techniques with moderate safety profiles.

  • Green: Employment of green chemistry or physical immobilization methods that minimize toxicity and environmental hazards.

Study-Specific Evaluation

For every study, each of the above variables has been assigned a score along with detailed annotations justifying the score. For example:

- *Study A* was assigned:

  • Sensitivity: Green (due to an LoD in the low ppb range),

  • Selectivity: Green (demonstrating robust interference mitigation),

- Response Time: Green (with a response time of less than 10 minutes),
- pH Range: Green (optimal performance within pH 6–8),
- Stability: Yellow (moderate stability under controlled conditions),
- Chromophore Type: Yellow (mixed use of synthetic and natural chromophores),
- Membrane Composition: Green (fully bio-based), and
- Immobilization Technique: Yellow (chemical methods with moderate safety).

- *Study B* received:
  - Response Time: Yellow (with response times between 10 and 60 minutes),
  - Working pH Range: Green (optimal within the 6–8 range), and
  - Immobilization Technique: Orange (due to the use of toxic cross-linkers), among other variable scores.

This supplementary material offers a transparent and reproducible framework for comparing sensor technologies, highlighting areas where improvements are needed and identifying the most promising approaches for community-based heavy metal monitoring in freshwater environments.