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Recent Advances in Functional Materials for Heavy Metal Ion Sensing: Progress and Prospects of Thiourea-Based Systems for Water Remediation

[Malaysian Journal of Chemistry](#) • Article • Open Access • 2026 • DOI: 10.55373/mjchem.v28i4.129 [Roslan, Norashikin](#)^a; [Ngah, Nurziana](#)^{a, b} ; [Hamid, Shafida Abd](#)^{a, b}; [Khodir, Wan Khartini Wan Abdul](#)^{a, b}; [Karim, Nurul Huda Abd](#)^c^a Department of Chemistry, Kulliyah of Science, International Islamic University Malaysia, Centre for Natural & Health Sciences, Jalan Sultan Ahmad Shah, Pahang, Kuantan, 25200, Malaysia[Show all information](#)

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Abstract

Water pollution caused by heavy metal ions (HMIs) and metal-oxoanions remains a major public health challenge due to their toxicity, persistence, and bioaccumulation. Various functional materials, including metal oxides, carbon-based nanomaterials, porous frameworks, polymers, and biopolymers, have been investigated for HMI sensing and removal. Their performance is governed primarily by the chemical identity, accessibility, and spatial organization of donor groups such as C=O , COOH , NH_2 , and SH , which mediate coordination, electrostatic, and hydrogen bonding (HB) interactions with target analytes. However, most reported systems remain single-purpose platforms focused either on sensing or adsorption, predominantly targeting metal cationic species under idealized laboratory conditions. Direct comparison of sensing and adsorption performance across studies is further complicated by inconsistent reporting units, variations in sample matrices, preconcentration procedures, pH conditions, and limited validation in real-water environments. In this context, sulfur- and nitrogen-containing moieties, particularly thiourea derivatives, are attractive due to their dual donor characteristics. The C=S group enables strong coordination with soft and borderline metal cations in accordance with Pearson's HSAB principle, whereas the NH group may potentially participate in directional HB with oxoanions. However, the practical significance of thiourea- NH -mediated oxoanion recognition in aqueous media remains insufficiently validated because strong solvent competition and oxoanion hydration weaken HB interactions. This review provides a critical and chemistry-based evaluation of thiourea-functionalized materials, including metal oxides, carbon-based materials, porous frameworks, and polymeric systems, focusing on how coordination chemistry, HB, hydration effects, charge transfer, and material architecture influence sensing and adsorption performance. Particular attention is given to the effects of competing ions, sample matrices, and experimental conditions on reported detection limits and adsorption capacities. In addition, this review discusses material stability, regeneration, ligand leaching, and environmental safety, highlighting the limited number of studies that evaluate real-water performance, interference resistance, and long-term reusability. Future strategies are proposed based on polymer-supported and solid-state thiourea architectures, preorganized multivalent HB arrays, electron-withdrawing group modulation, and integrated sensing-adsorption platforms capable of operating under realistic environmental conditions. Overall, this review establishes a rational framework for the development of robust, multifunctional thiourea-based materials for sustainable water monitoring and remediation applications aligned with Sustainable Development Goals (SDG) 6 (Clean Water and Sanitation) and 3 (Good Health and Well-Being). © 2026, Malaysian Institute of Chemistry. All rights reserved.

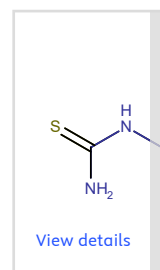
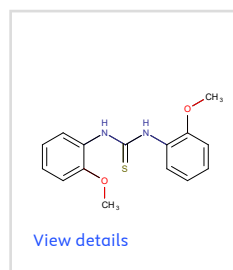
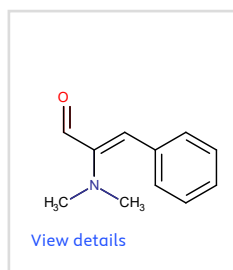
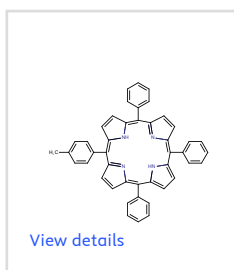
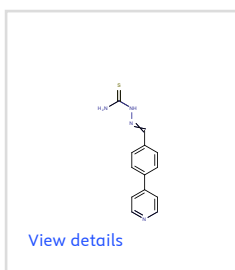
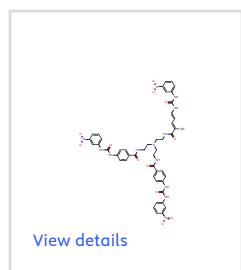
Author keywords

adsorption; functional materials; Heavy metal ions; hydrogen bonding; sensing; thiourea derivatives

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