International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

The Role of Surface Functionalization of Nanoplastics in Enhancing the Adsorption and Catalytic Reduction of Chromium (VI) by Supported Silver Nanoparticles: A Comparative Analysis

Muntaka Is-mail[1], Aaron Teye Caesar[2]

[1]Department of Chemistry, Kwame Nkrumah University of Science and Technology, Ghana
[2]Oklahoma State University, USA

Abstract

Hexavalent chromium (Cr(VI)) remains one of the most persistent and toxic environmental contaminants, driving urgent research into sustainable remediation strategies. This review critically examines the role of surface-functionalized nanoplastics as supports for silver nanoparticles (AgNPs) in enhancing Cr(VI) adsorption and catalytic reduction. Synthesizing evidence from 24 peer-reviewed studies published between 2010 and 2025, we evaluate how functional groups (–COOH, –NH_2, –OH, sulfonation) influence adsorption capacity, redox kinetics, recyclability, and stability. Functionalization was found to modulate surface charge, hydrophilicity, and electron transfer dynamics, with oxygen- and nitrogen-rich groups consistently delivering superior performance under acidic conditions. Comparative analyses reveal adsorption capacities up to 574 mg/g and rapid reduction efficiencies exceeding 95%, supported by pseudo-first- and second-order kinetic models. However, challenges remain in translating laboratory successes to real wastewater systems due to co-ion competition, natural organic matter fouling, and Ag^+ leaching. Furthermore, lifecycle risks posed by nanoplastic degradation and secondary microplastic release demand safe-by-design strategies and rigorous environmental validation. By integrating mechanistic insights with sustainability and scalability considerations, this review highlights functionalized nanoplastic–AgNP composites as promising yet transitional materials. Future directions include hybrid catalysts, biopolymer-derived supports, and policy frameworks to bridge the gap between innovation and real-world deployment.

Keywords: Chromium (VI) remediation, Nanoplastics, Silver nanoparticles, Surface functionalization, Environmental nanotechnology

Introduction

Hexavalent chromium (Cr(VI)) contamination remains one of the most intractable global environmental challenges due to its extreme toxicity, high solubility, oxidative potential, and bioaccumulative properties. Its widespread use in electroplating, leather tanning, pigment production, and mining has resulted in persistent discharges to aquatic and terrestrial ecosystems, with severe implications for public health.

Epidemiological evidence links Cr(VI) exposure to oxidative stress, DNA damage, and elevated cancer risk, while hotspot contamination events, such as groundwater concentrations reaching 20 mg/L in Jinzhou, China, underscore the scale and urgency of intervention (Tazhibayeva et al., 2025).

Conventional treatment methods, including chemical precipitation, ion exchange, and bioremediation, remain widely investigated for Cr(VI) remediation but are consistently constrained by secondary pollution, operational inefficiencies, and limited scalability. Chemical precipitation, while effective in reducing aqueous Cr(VI) concentrations, typically produces voluminous and toxic sludge that demands costly post-treatment and secure disposal, creating additional environmental burdens. Furthermore, precipitation efficiency is strongly pH-dependent and often compromised in real wastewater systems containing coexisting ions and organic matter. Ion exchange resins, though highly selective under controlled conditions, require extensive pretreatment of influent water to remove competing anions such as sulfate, chloride, or nitrate. The regeneration of resins demands concentrated eluents, which not only increase operational costs but also generate secondary brines rich in hazardous metals, complicating safe waste management. Bioremediation strategies, employing bacteria, fungi, or algae capable of enzymatic Cr(VI) reduction, are attractive due to their eco-friendly and low-energy characteristics. However, their application is limited by slow kinetics, narrow tolerance to fluctuating pH, salinity, and temperature, and difficulties in maintaining microbial viability in complex wastewater matrices. Moreover, large-scale implementation is hindered by the need for controlled bioreactors, potential pathogen risks, and extended treatment times that are incompatible with industrial-scale throughput. (V & AK, 2016) (Sharma et al., 2022). These limitations necessitate innovative, multifunctional remediation strategies.

Nanotechnology offers a disruptive alternative to conventional methods by exploiting nanoscale phenomena that integrate adsorption and catalytic reduction within a single multifunctional platform. Unlike traditional treatments that rely on isolated mechanisms, nanomaterials operate through synergistic pathways, enhancing efficiency, selectivity, and reusability. For instance, N-doped porous carbon and surface-modified TiO_2 have demonstrated rapid and highly selective detoxification of Cr(VI) under visible light irradiation, effectively reducing it to Cr(III), a less mobile and significantly less toxic species (Acharya et al., 2018; Huang et al., 2025). These hybrid photocatalytic–adsorptive systems illustrate how engineered nanomaterials can accelerate redox kinetics while simultaneously providing stable adsorption sites, thereby achieving higher removal efficiencies even under variable environmental conditions.

Extending this paradigm, nanoplastics have recently emerged as versatile and tunable supports for nanoparticle immobilization. Their intrinsic properties—including large specific surface area, customizable surface chemistry, and excellent dispersibility in aqueous environments—render them ideal carriers for stabilizing metallic nanoparticles. Functionalization with silver nanoparticles (AgNPs) further enhances these capabilities by introducing active redox centers that promote electron transfer to adsorbed Cr(VI) species. The resulting AgNP–nanoplastic composites exhibit superior dispersion stability, improved reusability across multiple treatment cycles, and enhanced catalytic turnover compared to unsupported AgNPs. Moreover, surface modifications can be tailored to control hydrophilicity, charge distribution, and functional group density, thereby optimizing electrostatic attraction of Cr(VI) oxyanions and facilitating multi-electron reduction pathways.

Recently, nanoplastics have gained attention as novel carriers and supports in water treatment systems. Their high surface area, tunable chemistry, and dispersibility make them ideal substrates for nanoparticle immobilization. When combined with silver nanoparticles (AgNPs), nanoplastics enhance reusability,

dispersion stability, and surface functionalization, enabling tailored interactions with Cr(VI) species (Javed and Lujanienė., 2025) (Rashid et al., 2025) (Avola et al., 2023).

Despite these advances, the mechanistic role of surface chemistry in AgNP–nanoplastic composites remains poorly understood. Functional groups, hydrophilicity, and charge distribution govern binding affinity, electron mobility, and catalytic turnover, yet systematic comparative studies are lacking. This review addresses this critical knowledge gap by evaluating how specific functionalization strategies modulate adsorption capacity, reduction efficiency, and stability in complex aqueous environments. By integrating insights from materials science, nanotechnology, and environmental chemistry, the review provides a framework for the rational design of next-generation nanocomposites, advancing the pursuit of scalable, sustainable, and safe Cr(VI) remediation technologies.

This review addresses a critical gap by systematically evaluating how surface functionalization strategies influence the performance of AgNP–nanoplastic composites in Cr(VI) remediation. It compares different surface chemistries to determine their effects on adsorption capacity, catalytic reduction efficiency, and stability in aqueous environments. By integrating perspectives from materials science, environmental chemistry, and nanotechnology, the review aims to guide the rational design of advanced nanocomposites for effective and sustainable Cr(VI) removal.

Methodology

This systematic review followed the PRISMA 2020 guidelines (Page et al., 2021) to identify and evaluate studies on nanoplastics (≤1000 nm) functionalized with polar or non-polar groups as supports for silver nanoparticles (AgNPs) in Cr(VI) remediation. Eligible studies reported quantitative outcomes including adsorption capacity (mg/g), observed rate constants (k_obs), reduction efficiency (%), and recyclability. Exclusion criteria included studies using non-AgNP catalysts, bulk plastics, or those lacking quantification of Cr(VI) removal.

Four databases; PubMed, Scopus, Web of Science, and Embase were searched using Boolean strings such as:

("nanoplastic functionalization" AND "silver nanoparticles" AND "chromium(VI)").

Searches were limited to peer-reviewed journal articles published between 2010 and 2025.

Data extraction was performed using a standardized form capturing: experimental conditions (pH, ionic strength, temperature), functionalization type (e.g., –COOH, –NH_2, –OH, sulfonation), AgNP loading, and characterization techniques (XPS, FTIR, TEM, BET). Two reviewers independently screened and extracted data, resolving discrepancies through consensus.

Study quality was assessed using an adapted Joanna Briggs Institute (JBI) tool for laboratory-based research, focusing on reproducibility, methodological transparency, and bias risk. A narrative synthesis was conducted, and where sufficient comparable data were available, a meta-analysis was performed to evaluate the influence of surface chemistry on Cr(VI) adsorption and reduction performance.

Results

A total of 90 records were identified through database searches (PubMed, Scopus, Web of Science, Embase). After removing duplicates and screening titles/abstracts, 24 full-text articles were assessed for eligibility (Page et al., 2021).

Most studies were published between 2018 and 2025, with research concentrated in China, India, and the EU. Nanoplastics used included polystyrene (PS), polyethylene (PE), and polypropylene (PP). AgNP

deposition was achieved via chemical reduction, photoreduction, or green synthesis using plant extracts (Carbajal-Morán et al., 2024).

Functionalization approaches included:

Oxygen-rich groups: –OH, –COOH (e.g., polydopamine coatings), Nitrogen groups: $–NH_2$, quaternary amines (e.g., chitosan, amine-grafted PAN), Sulfonation/halogenation: Enhanced hydrophilicity and electron-donating capacity, Plasma treatment/polymer grafting: Improved surface energy and AgNP anchoring.

Adsorption followed Langmuir or Freundlich isotherms, with capacities ranging from 52 to 574 mg/g depending on functionalization. Zeta potential values ranged from –15 to –45 mV, indicating stable colloidal dispersions (Singh et al., 2024).

Reduction kinetics were best described by pseudo-first-order or pseudo-second-order models, depending on the electron transfer mechanism. Functional groups facilitated electron shuttling, enhancing synergy between adsorption and reduction (Y. Gao et al., 2022) (Yang et al., 2021).

Among all functionalization strategies, –COOH and $–NH_2$ groups consistently yielded superior Cr(VI) removal efficiencies. These groups enhanced both adsorption affinity and redox potential, outperforming sulfonated and halogenated surfaces in acidic conditions. Plasma-treated surfaces showed improved recyclability but moderate removal rates. The comparative data suggest that dual-functionalized surfaces offer the best balance between performance and stability (Singh et al., 2024).

Cr(VI) removal efficiency was significantly influenced by environmental parameters. Optimal pH ranged from 2 to 4, where Cr(VI) exists predominantly as $HCrO_4^-$, favoring electrostatic interactions. Co-existing ions such as SO_4^{2-} and Cl^- competed for active sites, reducing efficiency by up to 20%. Elevated temperatures (30–50°C) enhanced reaction kinetics, while natural organic matter (NOM) introduced surface fouling, slightly diminishing performance (Y. Gao et al., 2022).

Toxicological risks associated with AgNP–nanoplastic composites include Ag^+ leaching and nanoplastic degradation. Studies reported Ag^+ release exceeding 0.1 µg/L under acidic conditions, posing ecological risks. Nanoplastics degrade under UV and oxidative stress, releasing secondary microplastics and additives, which may induce oxidative stress, genotoxicity, and endocrine disruption. These findings underscore the need for lifecycle assessments and safe-by-design strategies in nanocomposite development (Guar et al., 2025) .

Discussion

The adsorption and reduction of Cr(VI) by AgNP–nanoplastic composites are governed by a highly intricate interplay of surface chemistry, charge distribution, and electron transfer dynamics. Mechanistically, the surface charge of the nanoplastic substrate exerts a decisive influence on the affinity toward Cr(VI) oxyanions such as $HCrO_4^-$ and $Cr_2O_7^{2-}$, which are the predominant species under acidic conditions. Functionalization strategies that introduce positively charged moieties particularly through protonation of amino ($–NH_2$) or carboxyl (–COOH) groups have been consistently shown to enhance electrostatic attraction, thereby accelerating adsorption and facilitating subsequent reduction pathways. This effect is particularly pronounced in low-pH environments, where protonation increases both the density and distribution of active binding sites. (Fenti et al., 2020).

Beyond electrostatics, electron transfer dynamics between immobilized AgNPs and adsorbed Cr(VI) species are central to catalytic efficiency. Silver nanoparticles act as electron donors, enabling the reduction of Cr(VI) to Cr(III), which precipitates or adsorbs onto the nanoplastic surface as less mobile

and less toxic hydroxides or complexes. The nanoplastic support itself is not merely passive; functional groups such as –OH, sulfonates, and heteroatom dopants (e.g., N, S) mediate interfacial electron mobility, lower activation barriers, and stabilize transient intermediates. Density functional theory (DFT) simulations corroborate these findings, suggesting that functionalization reduces charge recombination rates and promotes multi-electron transfer, thereby enhancing overall catalytic turnover. (El Shahawy et al., 2022).

Moreover, the spatial distribution and density of AgNPs anchored to functionalized nanoplastics strongly influence reaction kinetics. Uniform dispersion prevents nanoparticle agglomeration, maximizes surface exposure, and maintains active catalytic sites. In contrast, poorly functionalized supports lead to aggregation, surface passivation, and diminished activity over successive cycles. The interplay of surface hydrophilicity and electron-rich functional domains also improves wettability and ion diffusion, enabling faster adsorption–reduction coupling.

Comparative analyses reveal that –COOH and $–NH_2$ functionalization consistently outperform sulfonated and halogenated surfaces in both adsorption and catalytic reduction. A study comparing UiO-66-based MOFs modified with different ligands found that $–NH_2$-modified frameworks achieved up to 97% Cr(VI) removal within minutes, attributed to strong ligand–metal interactions and enhanced electron transfer (N. Gao et al., 2023).

These experimental findings align with density functional theory (DFT) simulations, which provide molecular-level insights into binding affinities. It was demonstrated that functionalized nanocomposites with delocalized surface states exhibit stronger Cr(VI) adsorption and lower energy barriers for reduction, validating the observed experimental trends (Singh et al., 2024).

However, translating these lab-scale successes to real wastewater systems remains challenging. A systematic review of Cr(VI) remediation technologies over the past decade highlighted that while many materials perform well in controlled batch experiments, their efficacy diminishes in complex matrices containing competing ions, organic matter, and fluctuating pH. Moreover, scalability issues, lack of standardized functionalization protocols, and insufficient toxicity evaluations hinder industrial adoption (Kumari et al., 2025).

To address these limitations, future research should explore hybrid systems incorporating bimetallic catalysts such as Ag–Fe or Ag–Au, which offer enhanced redox activity and stability under diverse conditions. Additionally, the use of biopolymer-derived nanoplastics presents a sustainable alternative to synthetic supports, combining biodegradability with functional versatility. Long-term stability studies under environmental stressors like UV exposure, aging, and microbial degradation are also essential to ensure safe deployment in field applications (Yang et al., 2025).

In conclusion, while AgNP–nanoplastic composites show great promise for Cr(VI) remediation, optimizing surface functionalization and integrating theoretical modeling with environmental validation are critical for advancing their real-world applicability.

Conclusion

This review underscores the pivotal role of surface functionalization in enhancing the dual performance of adsorption and catalytic reduction in AgNP–nanoplastic composites for Cr(VI) remediation. Functional groups such as –COOH and $–NH_2$ not only improve electrostatic attraction toward Cr(VI) oxyanions ($HCrO_4^-$, $Cr_2O_7^{2-}$) but also facilitate electron transfer pathways that reduce Cr(VI) to the less toxic Cr(III).

These groups create favorable surface charges and redox-active sites, enabling synergistic interactions between the nanoplastic support and AgNPs.

Among the various strategies reviewed, oxygen- and nitrogen-rich functionalizations consistently demonstrated superior performance in both adsorption capacity and reduction kinetics. These modifications enhanced binding affinity, improved dispersion stability, and promoted catalytic activity, outperforming sulfonated, halogenated, and plasma-treated surfaces in most comparative studies.

The findings have significant research and policy implications. From a scientific perspective, they highlight the need for standardized functionalization protocols, integration of theoretical modeling, and long-term environmental assessments. From a regulatory standpoint, the results support the development of safe-by-design nanocomposite catalysts that minimize Ag^+ leaching and nanoplastic degradation while maintaining high remediation efficiency.

Future research should prioritize scalable synthesis methods, such as biopolymer-derived nanoplastics, and explore hybrid systems incorporating bimetallic catalysts (e.g., Ag–Fe, Ag–Au) to further enhance performance and environmental resilience. Ultimately, bridging the gap between laboratory innovation and field-scale application will be essential for deploying these materials in real-world water treatment systems.

References

1. (2025). *Review for "Recent Advances of Silver Nanoparticle-Based Polymer Nanocomposites for Biomedical Applications."* doi:10.1039/d4ra08220f/v2/review1
2. Avola, T., Campisi, S., Polito, L., Arici, S., Ferruti, L., & Gervasini, A. (2023a). Addressing the issue of surface mechanisms and competitive effects in Cr(VI) reductive-adsorption on tin-hydroxyapatite in the presence of co-ions. *Scientific Reports*, *13*(1). doi:10.1038/s41598-023-44852-7
3. Avola, T., Campisi, S., Polito, L., Arici, S., Ferruti, L., & Gervasini, A. (2023b). Addressing the issue of surface mechanisms and competitive effects in Cr(VI) reductive-adsorption on tin-hydroxyapatite in the presence of co-ions. *Scientific Reports*, *13*(1). doi:10.1038/s41598-023-44852-7
4. Carbajal Morán, H., Marquez Camarena, J. F., Galván Maldonado, C. A., & Zárate Quiñones, R. H. (2025). Advances in wastewater remediation using functionalized metallic and semiconductor nanomaterials: A systematic review. *Ecological Engineering & Environmental Technology*, *26*(2), 205–219. doi:10.12912/27197050/197170
5. Galant, K., Turosz, N., Chęcińska, K., Chęciński, M., Cholewa-Kowalska, K., Karwan, S., … Sikora, M. (2024a). Silver Nanoparticles (AgNPs) Incorporation into Polymethyl Methacrylate (PMMA) for Dental Appliance Fabrication: A Systematic Review and Meta-Analysis of Mechanical Properties. *International Journal of Molecular Sciences*, *25*(23), 12645. doi:10.3390/ijms252312645
6. Galant, K., Turosz, N., Chęcińska, K., Chęciński, M., Cholewa-Kowalska, K., Karwan, S., … Sikora, M. (2024b). Silver Nanoparticles (AgNPs) Incorporation into Polymethyl Methacrylate (PMMA) for Dental Appliance Fabrication: A Systematic Review and Meta-Analysis of Mechanical Properties. *International Journal of Molecular Sciences*, *25*(23), 12645. doi:10.3390/ijms252312645
7. Gaur, P., Raheja, Y., Regar, R. K., Singh, A., Kumari, K., Kumari, A., … Srivastava, J. K. (2025). Tiny Plastics, Massive Consequences: The Environmental and Health Crisis of Micro (Nano) Plastics. *Water, Air, & Soil Pollution*, *236*(11). doi:10.1007/s11270-025-08363-7

8. Huang, N., Chen, S., & Du, W. (2025). Efficient Photocatalytic Reduction of Cr(VI) on N-Doped Sludge/Cellulose-Derived Porous Carbon Using Synergistic Experimental–Deep Learning Approach. Retrieved from https://www.mdpi.com/2297-8739/12/9/247
9. Javed, M., & Lujanienė, G. (2025). Nanoplastics in aquatic systems: challenges and advances in adsorptive removal technologies. *Frontiers in Water*, *7*. doi:10.3389/frwa.2025.1611558
10. Kumari, A., Kamaraj, N., Selvaraj, R., & Nanoth, R. (2025). Emerging trends and future outlook on chromium removal in the lab, pilot scale, and industrial wastewater system: an updated review exploring 10 years of research. *Environmental Monitoring and Assessment*, *197*(5). doi:10.1007/s10661-025-13904-y
11. Nishad, V., Kumar, S., & Sastry, S. V. A. R. (2025). Kinetics, isotherms and thermodynamics studies of Cr (VI) removal using zero-valent iron nanoparticles synthesized from Aegle marmelos (Bael) plant extract. *Nanotechnology for Environmental Engineering*, *10*(3). doi:10.1007/s41204-025-00468-y
12. Ren, J., Zhang, S., Wang, Y., Shi, H., & Zhen, C. (2025). Cr(VI) Adsorption by Mg/Al Layered Double Hydroxide-Modified Sphagnum Moss Cellulose Gel: Performance and Mechanism. *Molecules*, *30*(8), 1796. doi:10.3390/molecules30081796
13. Singh, R., Chakma, S., & Birke, V. (2025). Implications of bi-metal catalysts on micro- and nano-zero-valent iron brands for hexavalent chromium removal in strongly alkaline and hyper-alkaline medium. *Environmental Science and Pollution Research*. doi:10.1007/s11356-025-36551-9
14. V, Y. (2017). Removal of Hexavalent Chromium by Adsorption Using Natural Wastes-A Review. *Advances in Recycling & Waste Management*, *02*(03). doi:10.4172/2475-7675.1000141
15. Yang, M., Zhang, X., & Sun, Y. (2024). Remediation of Cr(VI) Polluted Groundwater Using Zero-Valent Iron Composites: Preparation, Modification, Mechanisms, and Environmental Implications. *Molecules*, *29*(23), 5697. doi:10.3390/molecules29235697
16. Zhang, K., Zeng, X., Wang, J., Gan, M., Zhu, J., He, Q., … Fang, Y. (2025). Comparative mechanisms of Cr(VI) adsorption on biosynthetically derived Iron-minerals. *Journal of Central South University*, *32*(2), 376–391. doi:10.1007/s11771-025-5869-7
17. Zhigalenok, Y., Tazhibayeva, A., Kokhmetova, S., Starodubtseva, A., Kan, T., Isbergenova, D., & Malchik, F. (2025). Hexavalent chromium at the crossroads of science, environment and public health. *RSC Advances*, *15*(27), 21439–21464. doi:10.1039/d5ra03104d
18. Acharya, R., Naik, B., & Parida, K. (2018). Cr(VI) remediation from aqueous environment through modified-TiO2-mediated photocatalytic reduction. In *Beilstein Journal of Nanotechnology* (Vol. 9, Issue 1). https://doi.org/10.3762/bjnano.9.137
19. Avola, T., Campisi, S., Polito, L., Arici, S., Ferruti, L., & Gervasini, A. (2023). Addressing the issue of surface mechanisms and competitive effects in Cr(VI) reductive-adsorption on tin-hydroxyapatite in the presence of co-ions. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-44852-7
20. El Shahawy, A., Mubarak, M. F., El Shafie, M., & Abdulla, H. M. (2022). Fe(iii) and Cr(vi) ions' removal using AgNPs/GO/chitosan nanocomposite as an adsorbent for wastewater treatment. *RSC Advances*, *12*(27). https://doi.org/10.1039/d2ra01612e
21. Fenti, A., Chianese, S., Iovino, P., Musmarra, D., & Salvestrini, S. (2020). Cr(VI) sorption from aqueous solution: A review. In *Applied Sciences (Switzerland)* (Vol. 10, Issue 18). https://doi.org/10.3390/APP10186477

22. Gao, N., Guan, Q., & Kong, Z. (2023). A comparative study of confinement and layer modified Zr-based MOFs for the efficient removal of Cr(vi) from wastewater. *RSC Advances*, *13*(22). https://doi.org/10.1039/d3ra01308a
23. Gao, Y., Yang, X., Lu, X., Li, M., Wang, L., & Wang, Y. (2022). Kinetics and Mechanisms of Cr(VI) Removal by nZVI: Influencing Parameters and Modification. *Catalysts*, *12*(9). https://doi.org/10.3390/catal12090999
24. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. In *The BMJ* (Vol. 372). https://doi.org/10.1136/bmj.n71
25. Sharma, P., Singh, S. P., Parakh, S. K., & Tong, Y. W. (2022). Health hazards of hexavalent chromium (Cr (VI)) and its microbial reduction. In *Bioengineered* (Vol. 13, Issue 3). https://doi.org/10.1080/21655979.2022.2037273
26. Singh, S., Anil, A. G., Uppara, B., Behera, S. K., Nath, B., Pavithra, N., Bhati, S., Singh, J., Khan, N. A., & Ramamurthy, P. C. (2024). Adsorption and DFT investigations of Cr(VI) removal using nanocrystals decorated with graphene oxide. *Npj Clean Water*, *7*(1). https://doi.org/10.1038/s41545-024-00306-9
27. V, Y., & AK, P. (2016). Removal of Hexavalent Chromium (Cr6+) Using Different Natural Adsorbents - A Review. *Journal of Chromatography & Separation Techniques*, *08*(06). https://doi.org/10.4172/2157-7064.1000392
28. Yang, Q., Wang, H., Li, F., Dang, Z., & Zhang, L. (2021). Rapid and efficient removal of Cr(vi) by a core-shell magnetic mesoporous polydopamine nanocomposite: roles of the mesoporous structure and redox-active functional groups. *Journal of Materials Chemistry A*, *9*(22). https://doi.org/10.1039/d1ta02475b