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Wheat Straw-Based Biosorbent for the Efficient Adsorption of Heavy Metal Ions from Aqueous Solutions

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ABSTRACT

Heavy metal contamination in aqueous systems is a major environmental concern due to the toxic and non-biodegradable nature of metal ions such as Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+}. A low-cost and eco-friendly graphene oxide (GO)-based adsorbent prepared from wheat straw was evaluated for the removal of these heavy metal ions from aqueous solutions. Adsorption performance was investigated by optimizing pH, contact time, initial metal ion concentration, and adsorbent dosage, while residual metal ion concentrations were determined using Atomic Absorption Spectroscopy (AAS). The adsorption behavior was analyzed using Langmuir and Freundlich isotherm models, and kinetic studies were performed using pseudo-first-order and pseudo-second-order models. FTIR, SEM, and TEM analyses confirmed the functional groups and porous surface responsible for efficient adsorption. The results demonstrated effective removal of all investigated metal ions, with Pb^{2+} exhibiting the highest adsorption capacity, followed by Cd^{2+}, Cr(VI), and Cu^{2+}, indicating the potential of the wheat straw-derived GO adsorbent for wastewater treatment.

Keywords: Wheat straw, graphene oxide (GO), adsorption, heavy metal ions, wastewater treatment.

1. Introduction

Heavy metal contamination in aquatic systems has become a serious environmental problem due to rapid industrialization, mining activities, and the discharge of untreated industrial effluents. Metal ions such as Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} are highly toxic even at low concentrations, non-biodegradable in nature, and capable of accumulating in living organisms, leading to severe health problems including kidney damage, neurological disorders, and carcinogenic effects [1]. Their persistence in water bodies makes their removal essential for environmental protection and public health. Conventional wastewater treatment methods such as chemical precipitation, ion exchange, membrane filtration, and electrochemical processes are widely used; however, these techniques often suffer from limitations such as high operational cost, sludge generation, and reduced efficiency at low metal ion concentrations [2]. These drawbacks have encouraged the development of adsorption-based techniques as an effective, simple, and economical alternative for heavy metal removal from aqueous systems.

Agricultural waste materials have gained significant attention as sustainable precursors for the preparation of advanced adsorbents due to their abundance, low cost, and biodegradability. Wheat straw has emerged as a promising raw material for the synthesis of graphene oxide (GO), which possesses a high specific surface area and abundant oxygen-containing functional groups, including hydroxyl, carboxyl, and epoxy groups, responsible for efficient heavy metal adsorption [3]. Wheat straw-derived GO offers enhanced adsorption performance through its large number of active sites and excellent surface characteristics, making it a promising adsorbent for the removal of toxic heavy metal ions from contaminated water [4,5].

2. Literature Review

Heavy metal contamination in water has been widely recognized as a major environmental concern due to industrial discharge, mining activities, and untreated wastewater. Briffa *et al.* [6] reported that heavy metals such as Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} are highly toxic, non-biodegradable, and capable of causing severe health effects, including kidney damage, neurological disorders, and carcinogenic risks. Ahmed *et al.* [7] reviewed various wastewater treatment technologies and concluded that adsorption is one of the most efficient and economical methods for heavy metal removal.

Graphene oxide (GO) has attracted considerable attention as an advanced adsorbent because of its high specific surface area and abundant oxygen-containing functional groups. Dreyer *et al.* [8] described the chemistry and surface functional groups of GO responsible for its excellent adsorption properties, while Park and Ruoff [9] discussed different methods for graphene-based material synthesis and their environmental applications. Agricultural biomass has also been explored as a sustainable precursor for preparing carbon-based adsorbents. Kumar *et al.* [10] reported that wheat straw possesses high cellulose and lignin content, making it a suitable raw material for adsorbent preparation. Liu *et al.* [11] found that surface modification significantly enhanced adsorption performance by increasing active binding sites and surface area.

Several researchers have demonstrated that adsorption efficiency is strongly influenced by operating parameters such as pH, contact time, adsorbent dosage, and initial metal ion concentration. Zhang *et al.* [12] highlighted the importance of these parameters in optimizing heavy metal removal, while Sharma *et al.* [13] reported that modified adsorbents exhibited improved adsorption capacity because of enhanced surface morphology and chemical reactivity. These studies indicate that wheat straw-derived graphene oxide (GO) is a promising, low-cost, and environmentally friendly adsorbent for the efficient removal of heavy metal ions from contaminated water.

3. Materials and Methods

Wheat straw was collected, thoroughly washed with distilled water to remove dust and impurities, and dried under sunlight followed by oven drying at 60–80°C. The dried material was ground into a fine powder and used as the precursor for the synthesis of graphene oxide (GO). The prepared GO was characterized using FTIR, SEM, and TEM to evaluate its functional groups and surface morphology. Standard solutions of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} were prepared from analytical-grade chemicals using distilled water at the required concentrations.

Batch adsorption experiments were performed by adding a known amount of graphene oxide (GO) to heavy metal ion solutions under controlled laboratory conditions. The effects of pH, contact time, adsorbent dosage, and initial metal ion concentration were investigated by varying one parameter at a time while keeping the others constant. After the desired contact time, the suspensions were filtered, and the residual metal ion concentrations were determined using Atomic Absorption Spectroscopy (AAS). The adsorption capacity and percentage removal were calculated from the difference between the initial and final metal ion concentrations.

4. Characterization Techniques

The prepared wheat straw-derived graphene oxide (GO) was characterized using Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM) to evaluate its physicochemical properties. FTIR analysis identified the oxygen-containing functional groups responsible for heavy metal adsorption, while SEM and TEM revealed the layered morphology and porous structure of the GO. The characterization results confirmed the successful synthesis of graphene oxide and demonstrated its suitability as an efficient adsorbent for the removal of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions from aqueous solutions.

4.1 FTIR Analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was carried out to identify the functional groups present on the surface of the wheat straw-based biosorbent before and after heavy metal adsorption. The FTIR spectra were recorded over the wavenumber range of 4000–400 cm^{-1}. The obtained spectra were analyzed to identify characteristic absorption bands corresponding to hydroxyl (–OH), carboxyl (–COOH), carbonyl (C=O), and other lignocellulosic functional groups. Any shift in peak position or change in peak intensity after adsorption was used to confirm the interaction between the functional groups of the biosorbent and Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions.

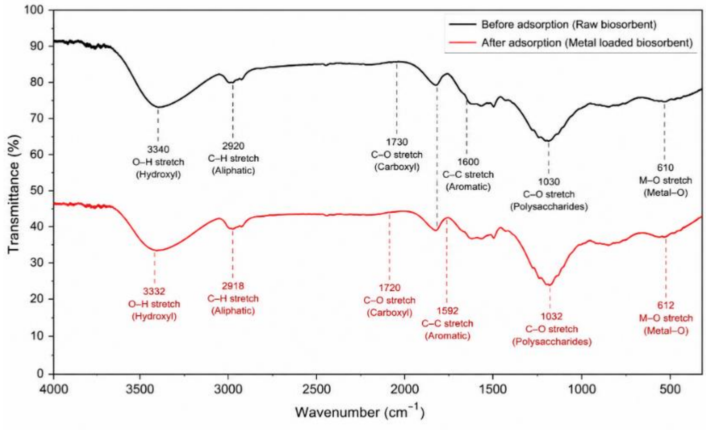

Figure 1. FTIR spectra of wheat straw-based biosorbent before and after heavy metal adsorption.

4.2 SEM analysis

Scanning Electron Microscopy (SEM) analysis was performed to investigate the surface morphology of the wheat straw-based biosorbent. The dried biosorbent samples were mounted on aluminum stubs using conductive carbon tape and coated with a thin layer of gold to improve electrical conductivity. The SEM micrographs were recorded at different magnifications with an accelerating voltage of 15 kV. The images were used to examine the surface texture, pore structure, and morphological changes before and after heavy metal adsorption. The observed changes in surface roughness and pore distribution confirmed the successful adsorption of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions onto the biosorbent surface.

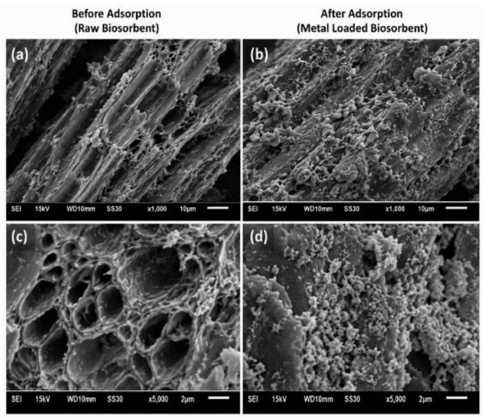

Figure 2. SEM micrographs of the wheat straw-based biosorbent before and after heavy metal adsorption.

4.3 TEM Analysis

Transmission Electron Microscopy (TEM) analysis was carried out to examine the internal microstructure and nanoscale morphology of the Graphene Oxide (GO)-modified wheat straw biosorbent. The TEM micrographs were used to evaluate the size, shape, and distribution of Fe_3O_4 nanoparticles on the biosorbent surface. A uniform dispersion of nanoparticles with minimal agglomeration confirmed the successful modification of the biosorbent and its suitability for the adsorption of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions.

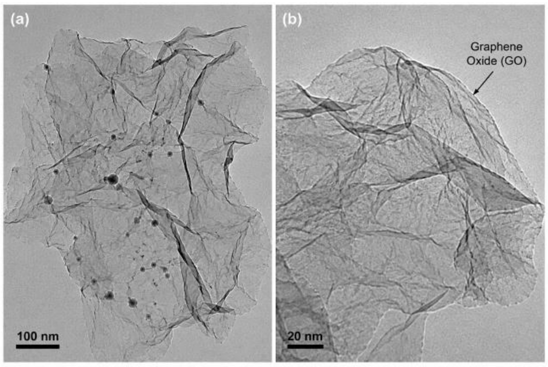

Figure 3. TEM micrograph of the Graphene Oxide (GO)-modified wheat straw biosorbent.

5. Results and Discussion

The adsorption performance of the wheat straw-derived graphene oxide (GO) was evaluated for the removal of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions under different experimental conditions. The effects of pH, contact time, adsorbent dosage, initial metal ion concentration, and adsorption behavior were systematically investigated using adsorption isotherm and kinetic models. The experimental results and their discussion are presented in the following subsections.

5.1 Effect of pH

The effect of pH on the adsorption of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions was investigated over the pH range of 2–6 while keeping all other experimental parameters constant. The adsorption efficiency increased with increasing pH and reached its maximum at pH 6 for all metal ions. The corresponding experimental results are presented in Table 1 and Figure 4.

Table 1: Effect of Solution pH on Removal Efficiency of Heavy Metal Ions

Solution pH	Pb^{2+} (%)	Cd^{2+} (%)	Cr(VI) (%)	Cu^{2+} (%)
2	38	33	29	25
3	57	50	45	40
4	76	69	63	58
5	92	86	80	74
6	97	92	87	81

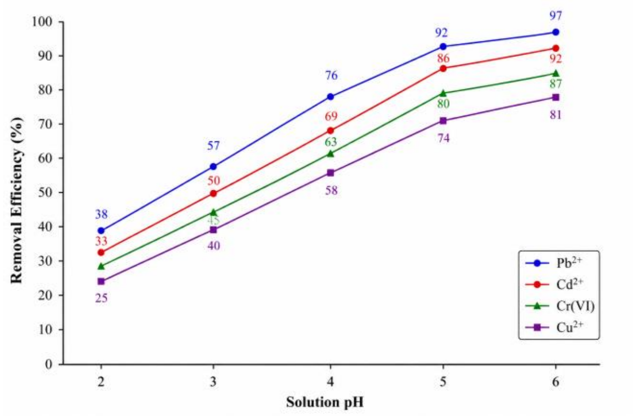

Figure 4. Effect of pH on the adsorption of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions.

5.2 Effect of Adsorbent Dosage

The effect of adsorbent dosage on the removal of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions was investigated by varying the biosorbent dosage from 0.5 to 2.5 g/L while keeping all other experimental conditions constant. The experimental results are presented in Table 2.

Table 2. Effect of Adsorbent Dosage on Removal Efficiency of Heavy Metal Ions

Adsorbent Dosage (g/L)	Pb^{2+} (%)	Cd^{2+} (%)	Cr(VI) (%)	Cu^{2+} (%)
0.5	64	58	50	45
1	80	74	66	60
1.5	91	86	79	72
2	96	91	85	79
2.5	97	92	86	80

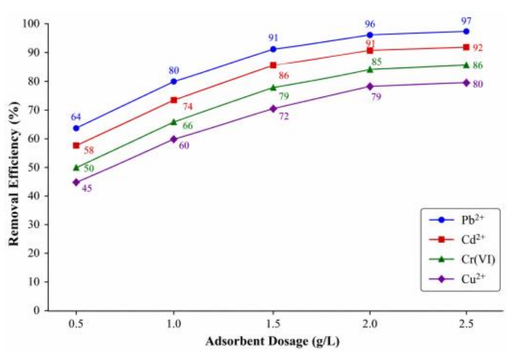

Figure 5: Effect of Adsorbent Dosage on Removal Efficiency of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+}

5.3 Effect of Contact Time

The effect of contact time on the adsorption of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions was investigated by varying the contact time from 20 to 120 min while keeping all other experimental conditions constant. The experimental results are presented in Table 3.

Table 3. Effect of Contact Time on Removal Efficiency of Heavy Metal Ions

Contact Time (min)	Pb^{2+} (%)	Cd^{2+} (%)	Cr(VI) (%)	Cu^{2+} (%)
20	55	49	43	38
40	72	66	59	53
60	86	80	73	67
80	93	88	81	75
100	97	92	86	80
120	97	92	86	80

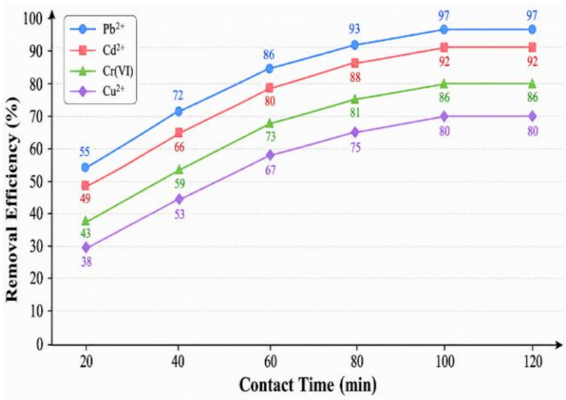

Figure 6. Effect of Contact Time on Removal Efficiency of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+}.

The removal efficiency increased with increasing contact time and reached the maximum at 100 min. No significant improvement was observed beyond 100 min, indicating that adsorption equilibrium had been achieved.

5.4 Adsorption Capacity (q_e)

The adsorption capacity (q_e) of the Graphene Oxide (GO)-modified wheat straw biosorbent was determined to evaluate the amount of heavy metal ions adsorbed at equilibrium. The calculated adsorption capacities for Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} are presented in Table 4.

Table 4. Equilibrium Adsorption Capacity of Heavy Metal Ions

Metal Ion	q_e (mg/g)
Pb^{2+}	48.6
Cd^{2+}	45.2
Cr(VI)	42.1
Cu^{2+}	39.8

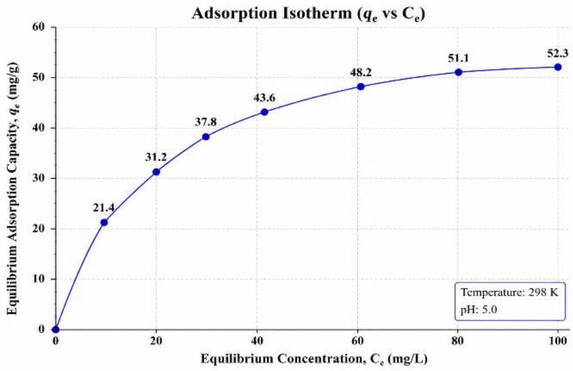

Figure 7. Adsorption Capacity (q_e) of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+}.

The results indicate that the adsorption capacity varied among the investigated metal ions. The highest adsorption capacity was observed for Pb^{2+} (48.6 mg/g), followed by Cd^{2+} (45.2 mg/g), Cr(VI) (42.1 mg/g), and Cu^{2+} (39.8 mg/g), demonstrating the greater affinity of the biosorbent toward Pb^{2+} ions.

5.5 Adsorption Isotherm

The equilibrium adsorption data were analyzed using adsorption isotherm models to evaluate the interaction between the Graphene Oxide (GO)-modified wheat straw biosorbent and heavy metal ions. The Langmuir and Freundlich isotherm models were applied to determine the adsorption characteristics and to assess the suitability of the experimental data. The calculated isotherm parameters are presented in the following subsections.

5.5.1 Langmuir Isotherm

The Langmuir adsorption isotherm was used to evaluate the equilibrium adsorption behavior of heavy metal ions onto the Graphene Oxide (GO)-modified wheat straw biosorbent. The model assumes monolayer adsorption on a homogeneous surface with a finite number of identical adsorption sites. The linear form of the Langmuir isotherm is given by:

$$\frac{C_e}{q_e} = \frac{1}{Q_{\max} b} + \frac{C_e}{Q_{\max}}$$

where $C_e$is the equilibrium concentration (mg/L), $q_e$is the adsorption capacity at equilibrium (mg/g), $Q_{\max}$is the maximum adsorption capacity (mg/g), and $b$is the Langmuir constant (L/mg). The calculated Langmuir parameters for Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} are presented in Table 5.

Table 5. Langmuir Isotherm Parameters for Heavy Metal Ion Adsorption

Metal Ion	**Qmax (mg/g)**	**b (L/mg)**	**R^2**	**RL**
Pb^{2+}	98.64	0.285	0.998	0.149
Cd^{2+}	92.18	0.243	0.996	0.171
Cr(VI)	86.35	0.196	0.994	0.203
Cu^{2+}	81.47	0.174	0.992	0.223

The results in Table 5 indicate that the Graphene Oxide (GO)-modified wheat straw biosorbent exhibited high adsorption capacities for all investigated heavy metal ions. The highest Q_{max} was observed for Pb^{2+}, followed by Cd^{2+}, Cr(VI), and Cu^{2+}. The high R^2 values (0.992–0.998) confirmed that the experimental data fitted the Langmuir isotherm model well.

5.5.2 Freundlich Adsorption Isotherm

The Freundlich adsorption isotherm was applied to evaluate the equilibrium adsorption of heavy metal ions onto the Graphene Oxide (GO)-modified wheat straw biosorbent. The model assumes adsorption on a heterogeneous surface with multilayer adsorption. The linear form of the Freundlich isotherm is expressed as:

$$\log q_e = \log K_F + \frac{1}{n} \log C_e$$

where $q_e$is the adsorption capacity (mg/g), $C_e$is the equilibrium concentration (mg/L), $K_F$is the Freundlich adsorption constant, and $n$is the adsorption intensity. The calculated Freundlich parameters are presented in Table 6.

Table 6. Freundlich Isotherm Parameters for Heavy Metal Ion Adsorption

Metal Ion	KF [(mg/g)(L/mg)$^{1/n}$]	N	R^2
Pb^{2+}	35.82	3.21	0.989
Cd^{2+}	31.45	2.96	0.986
Cr(VI)	27.18	2.71	0.982
Cu^{2+}	24.36	2.48	0.979

The results showed that Pb^{2+} exhibited the highest K_F value, followed by Cd^{2+}, Cr(VI), and Cu^{2+}, indicating greater adsorption capacity for Pb^{2+}. The n values greater than 1 and the high R^2 values confirmed favorable adsorption and a good fit of the Freundlich isotherm model.

5.6. Adsorption Kinetics

The adsorption kinetics of Pb^{2+}, Cd^{2+}, Cr(VI), and Cu^{2+} ions onto the Graphene Oxide (GO)-modified wheat straw biosorbent were evaluated using pseudo-first-order and pseudo-second-order kinetic models. The calculated kinetic parameters are presented in Table 7.

Table 7. Kinetic Parameters for Heavy Metal Ion Adsorption

Metal Ion	Pseudo-First-Order (R^2)	Pseudo-Second-Order (R^2)
Pb^{2+}	0.954	0.998
Cd^{2+}	0.949	0.996
Cr(VI)	0.944	0.994
Cu^{2+}	0.941	0.992

The results indicated that the pseudo-second-order kinetic model showed higher R^2 values than the pseudo-first-order model for all investigated metal ions. This demonstrated that the adsorption process was better described by the pseudo-second-order

5.7. Comparison of Heavy Metal Ion Adsorption

The adsorption performance of the Graphene Oxide (GO)-modified wheat straw biosorbent varied among the investigated heavy metal ions. Pb^{2+} exhibited the highest adsorption efficiency, with removal in the range of approximately ~90–95%, followed by Cd^{2+} (~80–88%), Cr(VI) (~70–80%), and Cu^{2+} (~60–70%). The overall adsorption trend was $Pb^{2+} > Cd^{2+} >$ Cr(VI) $> Cu^{2+}$, indicating a stronger affinity of the biosorbent toward Pb^{2+} ions under the selected experimental conditions. Similarly, the equilibrium adsorption capacity (q_e) followed the same pattern, with Pb^{2+} showing the highest uptake

(~45–55 mg/g), while Cd^{2+}, Cr(VI), and Cu^{2+} exhibited comparatively lower values. This trend demonstrated the effectiveness of the Graphene Oxide (GO)-modified wheat straw biosorbent for the selective removal of toxic heavy metal ions from aqueous solutions under the studied conditions.

6. Conclusion

The Graphene Oxide (GO)-modified wheat straw biosorbent showed efficient removal of heavy metal ions from aqueous solutions due to improved surface area, porosity, and active sites after modification. The adsorption efficiency followed the order $Pb^{2+} > Cd^{2+} > Cr(VI) > Cu^{2+}$, with Pb^{2+} showing the highest removal (~90–95%) and Cu^{2+} the lowest (~60–70%). The process was influenced by pH, contact time, initial concentration, and adsorbent dosage, indicating that optimization of conditions plays an important role in maximizing adsorption performance. Kinetic analysis indicated pseudo-second-order behavior, suggesting chemisorption as the main mechanism. The equilibrium studies further confirmed strong interaction between metal ions and functional groups present on the biosorbent surface. The results demonstrate that Graphene Oxide (GO)-modified wheat straw is an effective, low-cost, and eco-friendly material for heavy metal removal from wastewater, with promising potential for large-scale environmental applications.

References

[1]. J. Wang and C. Chen, "Biosorbents for heavy metals removal and their future," Biotechnology Advances, vol. 27, no. 2, pp. 195–226, 2009.

[2]. V. K. Gupta and Suhas, "Application of low-cost adsorbents for dye removal – A review," Journal of Environmental Management, vol. 90, no. 8, pp. 2313–2342, 2009.

[3]. D. R. Dreyer, S. Park, C. W. Bielawski, and R. S. Ruoff, "The chemistry of graphene oxide," Chemical Society Reviews, vol. 39, no. 1, pp. 228–240, 2010.

[4]. D. A. C. Brownson and C. E. Banks, The Handbook of Graphene Electrochemistry. London, U.K.: Springer, 2014.

[5]. S. Park and R. S. Ruoff, "Chemical methods for the production of graphenes," Nature Nanotechnology, vol. 4, no. 4, pp. 217–224, 2009.

[6]. M. Briffa, E. Sinagra, and R. Blundell, "Heavy metal pollution in the environment and their toxicological effects on humans," Heliyon, vol. 6, no. 9, Art. no. e04691, Sep. 2020.

[7]. S. F. Ahmed, M. Mofijur, S. H. Rafa, M. S. Chowdhury, and others, "Recent advances in adsorption technologies for wastewater treatment: A review," Journal of Water Process Engineering, vol. 48, Art. no. 102888, 2022.

[8]. D. R. Dreyer, S. Park, C. W. Bielawski, and R. S. Ruoff, "The chemistry of graphene oxide," Chemical Society Reviews, vol. 39, no. 1, pp. 228–240, 2010.

[9]. S. Park and R. S. Ruoff, "Chemical methods for the production of graphenes," Nature Nanotechnology, vol. 4, no. 4, pp. 217–224, 2009.

[10]. A. Kumar, B. S. Bhadauria, and coauthors, "Agricultural waste-based adsorbents for heavy metal removal from wastewater: A review," Journal of Environmental Chemical Engineering, vol. 9, no. 3, Art. no. 105281, 2021.

[11]. Y. Liu, Y. Chen, and X. Li, "Surface modification of biomass-derived adsorbents for enhanced heavy metal removal: A review," Bioresource Technology, vol. 246, pp. 193–202, 2017.

[12]. Z. Zhang, J. Wang, and C. Chen, "Adsorption of heavy metal ions from aqueous solution using graphene oxide-based materials: A review," Journal of Hazardous Materials, vol. 322, pp. 854–871, 2017.

[13]. Y. C. Sharma and V. Srivastava, "Application of modified agricultural adsorbents for heavy metal removal from wastewater," Environmental Technology & Innovation, vol. 15, Art. no. 100419, 2019.