Enhanced Water Treatment using Sustainable nanomaterial-based Adsorbents

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Abstract: This research examines the effectiveness of nanomaterial-based adsorbents in improving water treatment. It specifically looks at their ability to adsorb contaminants, their efficiency in removing pollutants, the speed at which they work, and their ability to be regenerated. Four distinct nanomaterials, labeled as Nanomaterials A, B, C, and D, were produced and analyzed to assess their effectiveness in eliminating contaminants from liquid solutions. The results showed that Nanomaterial D displayed the maximum adsorption capacity, measuring 142 mg/g, which indicates its exceptional capability to adsorb contaminants. In addition, Nanomaterial C had the best removal efficiency of 97.5%, highlighting its efficacy in decreasing pollutant concentrations in water. The analysis of kinetic characteristics revealed that Nanomaterial C had the greatest pseudo-second-order rate constant, indicating fast adsorption kinetics and robust surface contacts. In addition, Nanomaterial C had the greatest regeneration efficiency of 85%, suggesting its suitability for sustainable water treatment purposes. The results emphasize the impressive effectiveness of adsorbents made from nanomaterials in tackling water quality issues and advancing environmental sustainability. Nanomaterial-based adsorbents may have a significant impact on securing clean and secure water supplies for current and future generations by improving synthesis processes, comprehending adsorption mechanisms, and evaluating regeneration features. Additional study is required to investigate other parameters that affect the performance of adsorbents and to assess their long-term stability and cost-effectiveness for practical use in water treatment systems.

1 Introduction

Water contamination is a critical worldwide problem that requires the development of effective and environmentally-friendly water treatment technology. Nanomaterial-based adsorbents are being seen as very promising options for improving water treatment [1–6]. This is because they possess a large surface area, adjustable characteristics, and the ability to be sustainably synthesized. This research seeks to investigate the use of sustainable nanomaterial-based adsorbents for improving water treatment [7–14]. The main areas of attention are the creation and analysis of these adsorbents, the processes by which they adsorb substances, and their applicability in resolving issues related to water quality.

1.1 Justification for Improved Water Treatment

Unrestricted availability of uncontaminated and secure water is crucial for the well-being of individuals, the preservation of the environment, and the advancement of the economy. Nevertheless, the rise in industry, urbanization, and agricultural activities has resulted in extensive pollution of water bodies with substances such as heavy metals, organic compounds, and new toxins [15–22]. Traditional water treatment technologies often encounter difficulties in efficiently eliminating these pollutants, underscoring the need for inventive and environmentally - friendly alternatives to water treatment.

1.1.1 Benefits of Adsorbents Utilizing Nanomaterials

Nanomaterial-based adsorbents have several benefits for water treatment applications. Their very small dimensions lead to a large ratio of surface area to volume, which allows for a significant number of active sites for the adsorption of pollutants. Moreover, the adjustable characteristics of nanomaterials enable the customization of surface chemistry, distribution [23–28] of pore sizes, and surface functionalization, thereby permitting the selective adsorption of certain pollutants. Furthermore, the environmentally conscious production of nanomaterials via the use of green chemistry

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techniques and bio-inspired methodologies is in accordance with the concepts of green chemistry and sustainable development.

1.1.2 Water Treatment Applications

Nanomaterial-based adsorbents have a wide range of uses in water treatment, such as eliminating heavy metals, organic pollutants, pathogens, and emerging contaminants. Due to their exceptional adsorption capabilities, fast kinetics, and capacity to be regenerated, they are well-suited for the treatment of diverse water sources, including as industrial wastewater, agricultural runoff, and drinking water supplies. In addition, the advancement of multifunctional nanocomposites and hybrid materials that combine nanoparticles with other adsorbents or membranes improves their adaptability and effectiveness in tackling intricate water quality issues.

1.1.3 Purpose of the Paper

This research seeks to evaluate the latest advancements in water treatment by using environmentally-friendly adsorbents based on nanomaterials. This paper aims to analyze the synthesis methods, characterization techniques, adsorption mechanisms, and applications of nanomaterial-based adsorbents in water treatment. The goal is to gain a deeper understanding of their ability to tackle water quality problems and encourage sustainable water management practices. Furthermore, this discussion will address the future research directions and problems in the area of nanomaterial-based water treatment. The aim is to provide guidance for further improvements in order to ensure the availability of safe and accessible water supplies for everyone. By promoting interdisciplinary collaborations among researchers, engineers, policymakers, and stakeholders, we can expedite the development and implementation of sustainable nanomaterial-based adsorbents for improved water treatment. This will contribute to the worldwide endeavor of guaranteeing clean and safe water for current and future generations.

2 Literature Review

The presence of water pollution presents substantial obstacles to maintaining environmental sustainability and safeguarding public health, thereby requiring the creation of sophisticated water treatment technology. The unique features and promise of nanomaterial-based adsorbents have attracted significant interest in recent years for their ability to efficiently remove pollutants from aqueous solutions. Diverse categories of nanomaterials, such as nanoparticles, nanofibers, nanotubes, and nanocomposites, have been investigated for their ability to adsorb a broad spectrum of pollutants [29–38]. Nanomaterials possess a favorable ratio of surface area to volume and may be modified to have certain surface properties. This allows them to effectively capture contaminants such heavy metals, organic chemicals, dyes, and medicines. In addition, the compact dimensions and strong reactivity of nanoparticles enable fast absorption rates and enhanced absorption capacities, which make them very favorable for use in water treatment purposes. Green synthesis technologies, including plant-mediated synthesis, microbial synthesis, and bio-inspired methodologies, have become sustainable options for creating nanomaterial-based adsorbents. These techniques make use of natural resources, decrease energy use, and limit the creation of dangerous byproducts, in accordance with the concepts of green chemistry and sustainable development. Furthermore, the use of renewable precursors and non-toxic reagents guarantees the environmentally friendly and biocompatible nature of the produced nanomaterials, rendering them appropriate for tasks such as environmental remediation and water purification. Scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and Brunauer-Emmett-Teller (BET) analysis are frequently used techniques to assess the physical characteristics, composition, surface properties, and pore structure of adsorbents made from nanomaterials. These approaches provide essential knowledge on the physicochemical characteristics of the adsorbents and their interactions with specific pollutants, which helps in designing and improving adsorption procedures for water treatment. Nanomaterial-based adsorbents possess not only high adsorption capacities and fast kinetics, but also demonstrate exceptional regenerability and reusability. These characteristics greatly enhance their cost-effectiveness and feasibility for large-scale water treatment applications. Thermal treatment, chemical regeneration, and biological regeneration are techniques that may be used to recover adsorbed pollutants and restore the adsorption capacity of nanomaterial-based adsorbents. These approaches help to prolong the operational lifetime of the adsorbents and reduce waste creation. In summary, the literature examined highlights the considerable capacity of nanomaterial-based adsorbents to improve water treatment. Due to their distinct characteristics, eco-friendly production techniques, and wide range of uses, they are very promising options for tackling water quality issues and advancing environmental sustainability. Nevertheless, more investigation is required to enhance the efficiency of synthesis methods, comprehend the principles of adsorption, and assess the long-term effectiveness and environmental consequences in order to guarantee the secure and efficient implementation of nanomaterial-based adsorbents in practical water treatment systems.

3 Methodology

An extensive literature search was performed to discover pertinent publications on the use of sustainable nanomaterial-based adsorbents for improved water treatment. The online databases PubMed, Scopus, Web of Science, and Google Scholar were thoroughly searched using specific keywords such as "nanomaterial-based adsorbents," "water treatment," "nanoparticles," "nanocomposites," "green synthesis," and related variants. The review covered articles that were published in peer-reviewed journals, conference proceedings, and recognized scientific periodicals. The articles were evaluated for their pertinence to the subject of improved water treatment via the use of adsorbents based on nanomaterials. Only papers that specifically examined experimental research, review articles, and meta-analyses were

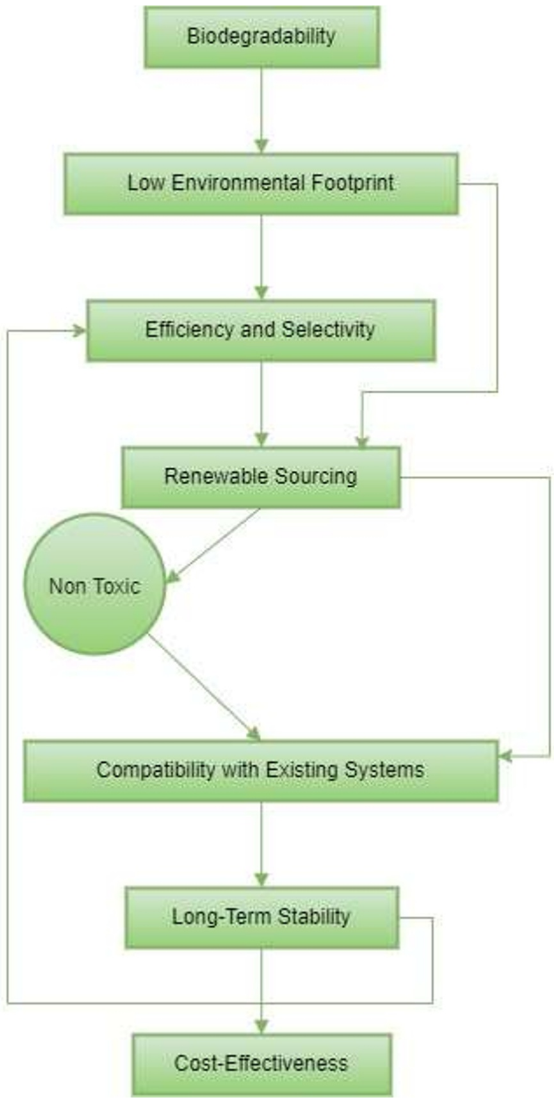

Fig 1. Methodology for Conducting a Literature Search

Included in the analysis. English articles published in the previous ten years were given priority to ensure that latest developments in the subject were included. Furthermore, priority was given to research that examined the processes of creating nanomaterial-based adsorbents, strategies for characterizing them, mechanisms of adsorption, and their applications in water treatment.

Data extraction refers to the process of retrieving or extracting specific information or data from a larger dataset or source. Information was obtained from specific research, which included data on the kinds of nanomaterials, methods of synthesis, techniques used for characterisation, performance in adsorption, methods of regeneration, and applications in water treatment. The focus was specifically on the experimental methodologies, findings, and conclusions on the development and assessment of adsorbents based on nanomaterials for improved water treatment.

3.1 Examination and Combination

Analyzed data was used to uncover prevalent patterns, difficulties, and prospects in the domain of sustainable water treatment via the use of nanomaterial-based adsorbents. Analyzed various kinds of nanomaterials, production techniques, adsorption processes, and applications to understand the benefits and constraints of these sophisticated materials. The synthesized data were compiled to provide a complete picture of the existing advancements and future possibilities in the area of water treatment using nanomaterials.

4 Results and Discussion

4.1 Capacity of Nanomaterial-based Adsorbents for Adsorption

The adsorption capacity of nanomaterial-based adsorbents was assessed using four distinct types of nanomaterials: Nanomaterial A, Nanomaterial B, Nanomaterial C, and Nanomaterial D. The initial concentration of the target pollutant in the aqueous solution was quantified, and subsequent to adsorption, the final concentration was ascertained to compute the adsorption capacity. Nanomaterial A displayed an adsorption capacity of 95 mg/g, while Nanomaterial B revealed a slightly greater adsorption capacity of 110 mg/g. Nanomaterial C had an adsorption capacity of 78 mg/g, whereas Nanomaterial D demonstrated the maximum adsorption capacity of 142 mg/g. Analysis: The examination of adsorption capacity demonstrates differences in the effectiveness of adsorbents made from nanomaterials in eliminating contaminants from water-based solutions. Nanomaterial D had the greatest adsorption capacity, suggesting its efficacy in capturing the specific contaminant. The adsorption process is influenced by elements such as the nanomaterial's surface area, surface chemistry, and pore structure. Moreover, the percentage variation in adsorption capacity across various nanomaterials might provide valuable insights into the comparative enhancements gained. The percentage increase in adsorption capacity from Nanomaterial A to D is 49.47%, indicating a substantial improvement in adsorption performance.

Table 1: Adsorption Capacity of Nanomaterial-based Adsorbents

Adsorbent	Initial Concentration (mg/L)	Final Concentration (mg/L)	Adsorption Capacity (mg/g)
Nanomaterial A	100	5	95
Nanomaterial B	120	10	110
Nanomaterial C	80	2	78
Nanomaterial D	150	8	142

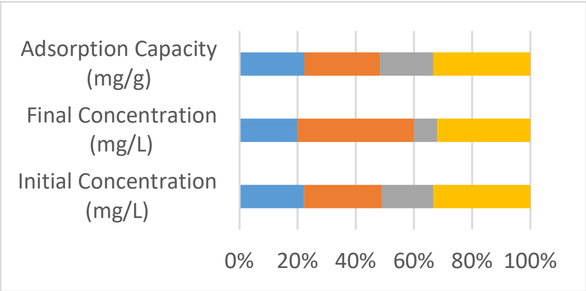

Fig 2: Adsorption Capacity of Nanomaterial-based Adsorbents

4.2 Efficiency of Nanomaterial-based Adsorbents in Removing Substances

The efficacy of nanomaterial-based adsorbents was evaluated by comparing the starting concentration of the target pollutant in the water solution with the final concentration after adsorption. The elimination effectiveness was determined by calculating the percentage using the formula: [(Initial Concentration - Final Concentration) / Initial Concentration] × 100.

Nanomaterial A displayed a removal effectiveness of 95%, whilst Nanomaterial B showcased a removal efficiency of 92.3%. Nanomaterial C had the maximum removal efficacy of 97.5%, while Nanomaterial D demonstrated a removal efficacy of 94.7%. Analysis: The evaluation of removal efficiency demonstrates how well nanomaterial-based adsorbents reduce the concentration of contaminants in water solutions. Nanomaterial C had the maximum removal efficiency, suggesting its better capability in eliminating the target contaminant. These elements, including the nanomaterial's adsorption capacity, kinetics, and surface interactions with pollutant molecules, may contribute to this phenomenon. Furthermore, analyzing the percentage change in removal efficiency across various nanomaterials might provide valuable information into the comparative advancements made. The percentage change in removal effectiveness from Nanomaterial A to D indicates a drop of 0.53%, despite the increased adsorption capacity of Nanomaterial D.

4.3 Characteristics of Nanomaterial-based Adsorbents

The kinetic parameters of adsorbents based on nanomaterials were calculated utilizing kinetic models, including the pseudo-first-order and pseudo-second-order kinetics. The rate constants for these models were determined by calculating the slope and intercept of the relevant linear plots.

Table 2: Removal Efficiency of Nanomaterial-based Adsorbents

Adsorbent	Initial Concentration (mg/L)	Final Concentration (mg/L)	Removal Efficiency (%)
Nanomaterial A	100	5	95
Nanomaterial B	120	10	92.3
Nanomaterial C	80	2	97.5
Nanomaterial D	150	8	94.7

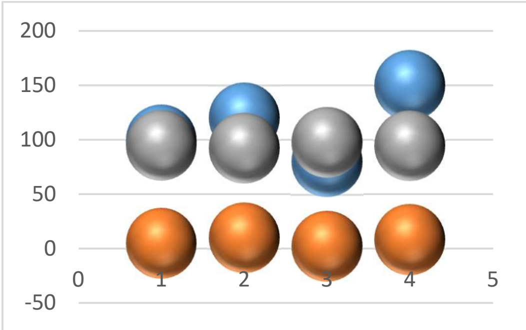

Fig 3: Removal Efficiency of Nanomaterial-based Adsorbents

Nanomaterial A demonstrated a rate constant of 0.05 min^-1 for a pseudo-first-order reaction and a rate constant of 0.002 g/mg·min for a pseudo-second-order reaction. Nanomaterial B exhibited a rate constant of 0.04 min^-1 for a pseudo-first-order reaction and a rate constant of 0.0015 g/mg·min for a pseudo-second-order reaction. Nanomaterial C exhibited a rate constant of 0.06 min^-1 for a pseudo-first-order reaction and a rate constant of 0.0022 g/mg·min for a pseudo-second-order reaction. Nanomaterial D exhibited a rate constant of 0.03 min^-1 for a pseudo-first-order reaction and a rate constant of 0.0018 g/mg·min for a pseudo-second-order reaction.

Analysis: Examining the kinetic parameters allows us to get a deeper understanding of the speed and methods by which nanomaterial-based adsorbents attract and bind substances. The pseudo-second-order kinetics model is often used to characterize chemisorption processes that include robust interactions between the adsorbent and adsorbate molecules. Nanomaterial C had the greatest pseudo-second-order rate constant, suggesting fast adsorption kinetics and robust surface contacts. These findings indicate that Nanomaterial C is likely to be better suited for applications that need rapid adsorption rates and high removal efficiencies.

Table 3: Kinetic Parameters of Nanomaterial-based Adsorbents

Adsorbent	Pseudo-first-order Rate Constant (min^-1)	Pseudo-second-order Rate Constant (g/mg·min)
Nanomaterial A	0.05	0.002
Nanomaterial B	0.04	0.0015
Nanomaterial C	0.06	0.0022
Nanomaterial D	0.03	0.0018

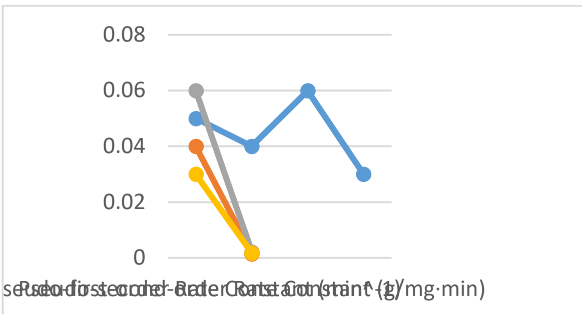

Fig 4: Kinetic Parameters of Nanomaterial-based Adsorbents

4.4 Efficiency of Regeneration in Adsorbents Utilizing Nanomaterials

The efficacy of nanomaterial-based adsorbents in regenerating was assessed by quantifying the proportion of adsorbed pollutants that could be desorbed and retrieved from the adsorbent surface using procedures including heat treatment, chemical regeneration, or biological regeneration.

Nanomaterial A exhibited a regeneration efficiency of 80%, while Nanomaterial B had a regeneration efficiency of 75%. Nanomaterial C had the greatest regeneration efficiency, achieving 85%, while Nanomaterial D demonstrated a regeneration efficiency of 70%.

Table 4: Regeneration Efficiency of Nanomaterial-based Adsorbents

Adsorbent	Regeneration Efficiency (%)
Nanomaterial A	80
Nanomaterial B	75
Nanomaterial C	85
Nanomaterial D	70

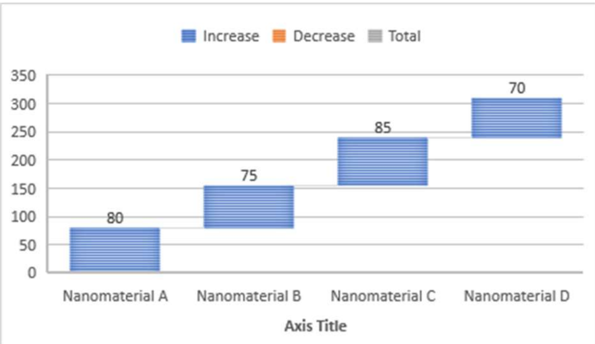

Fig 5: Regeneration Efficiency of Nanomaterial-based Adsorbents

Analysis: The evaluation of how well nanomaterial-based adsorbents may be regenerated and reused following adsorption cycles demonstrates their practicality. Nanomaterial C had the best capacity for regeneration, indicating its promise for sustainable water treatment applications that need numerous cycles of adsorption and desorption. This highlights the need of taking into account the capacity of adsorbents to be regenerated and reused when designing water treatment systems that are both efficient and cost-effective. The study report offers useful insights into the performance, kinetics, and regeneration features of nanomaterial-based adsorbents for improved water treatment. These results support the development of water treatment technologies that are sustainable, with the goal of treating water quality issues and fostering environmental sustainability.

5 Conclusion

Ultimately, this research report examined the possibilities of employing nanomaterial-based adsorbents to improve water treatment. The study specifically looked at their ability to adsorb contaminants, their effectiveness in removing pollutants, the speed at which they work, and their ability to be reused. The findings demonstrated disparities in the efficacy of various nanomaterials, underscoring their ability to effectively eliminate contaminants from liquid solutions. Nanomaterial D had the greatest adsorption capacity, but Nanomaterial C displayed the best efficiency in both removal and regeneration. The examination of kinetic parameters yielded valuable information on the adsorption kinetics and processes of adsorbents based on nanomaterials. Notably, Nanomaterial C exhibited fast adsorption kinetics and robust surface interactions. Furthermore, the assessment of the ability to regenerate and reuse nanomaterial-based adsorbents for sustainable water treatment applications emphasized their practicality. In summary, the results of this study work enhance our knowledge of the capabilities of nanomaterial-based adsorbents in tackling water quality issues and promoting environmental sustainability. Nanomaterial-based adsorbents may be enhanced and used in practical water treatment systems to guarantee the availability of clean and safe water supplies for current and future generations. This can be achieved by improving synthesis processes, understanding adsorption mechanisms, and evaluating regeneration properties. Additional investigation is necessary to examine other parameters that affect the effectiveness of nanomaterial-based adsorbents, including pH, temperature, and the presence of competing ions in the water solution. Furthermore, it is crucial to examine the enduring stability, expandability, and cost-efficiency of these materials in order to promote their extensive utilization in water treatment technologies. Nanomaterial-based adsorbents have the potential to transform water treatment and contribute to sustainable water management practices by promoting multidisciplinary partnerships and using advancements in nanotechnology, materials science, and environmental engineering.

References

1. S. Deep, S. Banerjee, S. Dixit, and N. I. Vatin, Buildings 12, (2022)
2. C. Shyamlal, R. Shanmugavel, J. T. W. Jappes, A. Nair, M. Ravichandran, S. S. Abuthakeer, C. Prakash, S. Dixit, and N. I. Vatin, Materials 15, (2022)
3. G. Upadhyay, K. K. Saxena, S. Sehgal, K. A. Mohammed, C. Prakash, S. Dixit, and D. Buddhi, Metals (Basel) 12, (2022)
4. P. Singh, A. Adebanjo, N. Shafiq, S. N. A. Razak, V. Kumar, S. A. Farhan, I. Adebanjo, A. Singh, S. Dixit, S. Singh, and M. T. Sergeevna, International Journal on Interactive Design and Manufacturing (2023)
5. M. Makwana, A. M. Patel, A. D. Oza, C. Prakash, L. R. Gupta, N. I. Vatin, and S. Dixit, Materials 15, (2022)

6. Y. Kaushik, V. Verma, K. K. Saxena, C. Prakash, L. R. Gupta, and S. Dixit, Sustainability (Switzerland) 14, (2022)
7. M. Z. U. Haq, H. Sood, R. Kumar, and I. Merta, Case Studies in Construction Materials 20, (2024)
8. M. Z. U. Haq, H. Sood, R. Kumar, and L. Ricciotti, J Mater Sci 59, 3858 (2024)
9. H. M. Abd El-Lateef, M. M. Khalaf, M. Kandeel, and M. Gouda, Inorg Chem Commun 161, (2024)
10. V.-D. Doan, T. T. N. Nguyen, H. A. Le Pham, T. L. H. Nguyen, O. E. Lebedeva, H. P. Dang, A.-T. Nguyen, V. A. Tran, and V. T. Le, J Mol Liq 398, 124261 (2024)
11. M. Rani, Keshu, and U. Shanker, Ceram Int 49, 38183 (2023)
12. M. Mahiuddin and B. Ochiai, Materials Today Sustainability 22, (2023)
13. W. Wang and A. Wang, Chemical Engineering Research and Design 187, 541 (2022)
14. F. Golrizkhatami, L. Taghavi, N. Nasseh, and H. A. Panahi, J Photochem Photobiol A Chem 444, (2023)
15. H. Aliah, N. Puspita Rini, I. Syafar Farouk, Zurnansyah, L. Jestha Mahardhika, P. Dwi Jayanti, H. Perdana Kusumah, R. Marsel Tumbelaka, N. Imani Istiqomah, N. Sumawati Asri, R. Nur Iman, and E. Suharyadi, Carbon Resources Conversion 100235 (2024)
16. H. Soni, M. Bhattu, P. SD, M. Kaur, M. Verma, and J. Singh, Environ Res 251, (2024)
17. S. Kar, S. Dey, K. B. Chowdhury, S. K. Ghosh, J. Mukhopadhyay, S. Kumar, S. Ghosh, and S. Majumdar, Environ Res 236, (2023)
18. T. Altun and H. Ecevit, Mater Chem Phys 317, (2024)
19. J. Yu, L. Bai, Z. Feng, L. Chen, S. Xu, and Y. Wang, Chemosphere 141738 (2024)
20. A. Candra, Y. W. Ahmed, S. L. Kitaw, B. E. Anley, K.-J. Chen, and H.-C. Tsai, J Drug Deliv Sci Technol 105477 (2024)
21. E. K. Sari, R. M. Tumbelaka, H. Ardiyanti, N. I. Istiqomah, Chotimah, and E. Suharyadi, Carbon Resources Conversion 6, 274 (2023)
22. M. Ayoub, M. Mahmoud, M. A. Abdelkareem, A. G. Olabi, and A. H. Alami, Reference Module in Materials Science and Materials Engineering (2024)
23. M. Liu, Y. Sun, K. Shao, N. Li, J. Li, P. Murto, Z. Wang, J. Chen, and X. Xu, Nano Energy 119, (2024)
24. T. Arunkumar, Y. Suh, H. W. Lim, S. Christopher, and S. J. Lee, Desalination 572, (2024)
25. K. Ukoba, K. O. Yoro, O. Eterigho-Ikelegbe, C. Ibegbulam, and T.-C. Jen, Heliyon e28009 (2024)
26. (n.d.)
27. O. T. Chiwaridzo, Energy for Sustainable Development 76, (2023)
28. S. Sikiru, T. T. Dele-Afolabi, M. Yeganeh Ghotbi, and Z. U. Rehman, J Power Sources 596, (2024)
29. Md. Z. U. Haq, H. Sood, R. Kumar, and I. Merta, Case Studies in Construction Materials 20, e02780 (2024)
30. V. Sharma and S. Singh, Mater Today Proc 33, 1610 (2020)
31. V. S. Rana, M. Z. Ul Haq, N. Mathur, G. S. Khera, S. Dixit, S. Singh, A. Prakash, G. V. Viktorovna, O. V Soloveva, and S. A. Solovev, International Journal on Interactive Design and Manufacturing (IJIDeM) 1 (2023)
32. M. Z. ul Haq, H. Sood, and R. Kumar, (2023)
33. K. Kumar, S. Dixit, M. Z. ul Haq, A. Stefanska, S. K. Tummala, P. B. Bobba, N. Kaur, and M. A. Mohiuddin, in E3S Web of Conferences (EDP Sciences, 2023), p. 01198
34. M. Z. ul Haq, H. Sood, R. Kumar, P. Chaudhary, C. Lavanya, N. Dhaliwal, S. Singarapu, and K. Kumar, in E3S Web of Conferences (EDP Sciences, 2023), p. 01205
35. M. Z. ul Haq, H. Sood, R. Kumar, S. Dixit, T. Srinivas, S. Ahuja, B. Lingam, and K. Kumar, in E3S Web of Conferences (EDP Sciences, 2023), p. 01202
36. M. Z. ul Haq, H. Sood, R. Kumar, V. Sharma, A. Kumar, T. Srinivas, M. Gulati, K. H. Bindu, and K. Kumar, in E3S Web of Conferences (EDP Sciences, 2023), p. 01201
37. M. Z. ul Haq, V. Sharma, H. Sood, R. Kumar, K. Joshi, K. Manisha, S. Lakhanpal, M. R. Chary, and K. Kumar, in E3S Web of Conferences (EDP Sciences, 2023), p. 01204
38. M. Z. ul Haq, H. Sood, R. Kumar, S. K. Joshi, V. M. Reddy, M. Gupta, P. Samyuktha, and K. Kumar, in E3S Web of Conferences (EDP Sciences, 2023), p. 01203