JPPIPA 12(4) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Hybrid Review: Research Trends Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics

Susilawati[1*], Muhammad Taufik[1], Teguh Ardianto[2], Syarful Annam[3]

[1] Physics Education Department, FKIP, Universitas Mataram, Mataram, Indonesia.
[2] Department of Physics, Universitas Mataram, Mataram, Indonesia.
[3] Sciences Education Department, Universitas Negeri Makasar, Makassar, Indonesia.

Received: February 07, 2026
Revised: March 16, 2026
Accepted: April 25, 2026
Published: April 30, 2026

Corresponding Author:
Susilawati
susilawatihambali@unram.ac.id

DOI: 10.29303/jppipa.v12i4.14545

Open Access

Abstract: The increasing discharge of dye-contaminated wastewater from the textile industry poses serious environmental and health challenges, necessitating the development of efficient, sustainable, and reusable treatment materials. This study presents a hybrid review integrating a Systematic Literature Review (SLR) and bibliometric analysis to critically examine research trends, material design strategies, adsorption mechanisms, and existing limitations of magnetic nanocomposite adsorbents for textile dye wastewater treatment. Following the PRISMA 2020 guidelines, 30 peer-reviewed articles published between 2018 and 2025 were systematically selected for SLR from Scopus and SINTA databases and 200-500 articles for bibliometric analysis. Bibliometrics focuses on Scopus data (to identify global trends), while SINTA is used to strengthen SLR in the local context of the Indonesian textile industry. Bibliometric mapping using VOSviewer reveals a growing research emphasis on multifunctional materials, regeneration performance, and sustainability, while the SLR highlights a dominant focus on binary nanocomposite systems and single-dye adsorption studies under idealized laboratory conditions. A significant research gap is identified in the integration of complex tungsten–tantalum oxide phases with magnetic Fe_3O_4 matrices. Addressing this gap, this review identifies the integration of complex tungsten–tantalum oxide phases as a promising future research direction to overcome current limitations in chemical stability and improved resistance to harsh textile wastewater environments. The findings provide strategic insights for the design of next-generation magnetic adsorbents with improved industrial applicability and environmental sustainability.

Keywords: Dye Adsorption; Fe_3O_4; Magnetic nanocomposites; Textile wastewater; Tungsten–tantalum oxide

Introduction

The textile and weaving industry is one of the manufacturing sectors that significantly contributes to aquatic environmental pollution, particularly through the discharge of wastewater containing high concentrations of synthetic dyes. Textile dyes such as azo dyes, reactive dyes, and basic dyes possess complex aromatic structures, high chemical stability, and resistance to natural degradation, allowing them to persist in aquatic environments for extended periods (Ahmed & Hameed, 2018; Zhang et al., 2018). The presence of synthetic dyes in wastewater not only deteriorates the aesthetic quality of water bodies but also reduces light penetration, disrupts photosynthetic activity in aquatic ecosystems, and poses toxic,

How to Cite:
Susilawati, Taufik, M., Ardianto, T., & Annam, S. (2026). Hybrid Review: Research Trends Fe3O4-WTa37O95.487 Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics. *Jurnal Penelitian Pendidikan IPA*, *12*(4), 40–51. https://doi.org/10.29303/jppipa.v12i4.14545

mutagenic, and carcinogenic risks to humans and aquatic organisms (Wang et al., 2020; Zhang et al., 2021).

Various wastewater treatment technologies have been implemented to address this issue, including coagulation–flocculation, advanced oxidation processes, biological treatments, and membrane-based technologies. However, these methods often suffer from significant limitations, such as high operational costs, secondary sludge generation, low efficiency at high dye concentrations, and operational complexity (Rahman & Abdullah, 2023; Wu et al., 2020). In this context, adsorption remains one of the most effective and flexible approaches for textile dye wastewater treatment due to its high removal efficiency, operational simplicity, and adaptability to different types of contaminants (Juang et al., 2018; Mohapatra & Anand, 2021).

Advances in materials science have promoted the use of nanomaterials as next-generation adsorbents for wastewater treatment. Nanomaterials offer unique advantages, including high specific surface area, abundant active sites, and strong interactions with pollutant molecules (Sadegh et al., 2023; Wu & Zhao, 2023). Among the various nanomaterials developed, magnetite-based magnetic nanoparticles (Fe_3O_4) have emerged as one of the most promising materials for dye adsorption applications. Fe_3O_4 nanoparticles exhibit superparamagnetic behavior, good chemical stability, and enable rapid and efficient separation of the adsorbent from aqueous media using an external magnetic field (Zhao et al., 2020; Niculescu et al., 2024). Numerous studies have reported the successful application of Fe_3O_4 nanoparticles for dye removal from wastewater. Liu et al. (2019a) and Zhang et al. (2018) demonstrated that Fe_3O_4 enhances dye adsorption efficiency through electrostatic interactions and surface binding mechanisms. Nevertheless, the direct use of pristine Fe_3O_4 nanoparticles is often limited by particle agglomeration, restricted active sites, and reduced adsorption performance after repeated use (Patel & Suresh, 2019; Li et al., 2022). Consequently, the development of Fe_3O_4-based magnetic nanocomposites has become an important strategy to improve structural stability and adsorption performance.

The integration of Fe_3O_4 with various supporting materials such as activated carbon, graphene oxide, conductive polymers, biopolymers, and natural minerals has been shown to significantly enhance adsorption capacity and selectivity toward different dyes (Yang et al., 2019; Li et al., 2021; Singh et al., 2022). Juang et al. (2018) and Wu et al. (2024) reported that Fe_3O_4 composites with porous carbon and biochar increase surface area and facilitate dye diffusion into the adsorbent structure. In addition, the incorporation of biopolymers and functional polymers into Fe_3O_4 nanocomposite systems improves the sustainability and environmental compatibility of the adsorbent materials (Mayangsari et al., 2025; Hennaoui et al., 2024).

In recent years, research attention has increasingly focused on magnetic nanocomposites based on complex metal oxides with multifunctional properties. Transition metal oxides such as tungsten and tantalum oxides are known for their high structural stability, unique electronic properties, and strong surface interactions with charged organic compounds (Zhang et al., 2020; Patel et al., 2024). The integration of complex metal oxides with Fe_3O_4 not only enhances adsorption capacity but also broadens the operational stability of the adsorbent under extreme pH conditions and complex ionic environments (Jiang et al., 2023; Kumar et al., 2023).

Magnetic Fe_3O_4-based nanocomposites incorporating metal oxides have also demonstrated potential as multifunctional adsorbents with catalytic activity and excellent regeneration performance. Said et al. (2025) and Sultana et al. (2025) reported that Fe_3O_4 nanocomposites derived from metal–organic frameworks and metal oxides maintained high adsorption efficiency over multiple regeneration cycles, making them particularly suitable for industrial applications. Other studies have shown that combining Fe_3O_4 with inorganic matrices and natural minerals enhances mechanical stability and magnetic separation efficiency of the adsorbents (Foo & Hameed, 2018; Wu et al., 2022; Ghoohestani et al., 2024).

Despite the extensive development of Fe_3O_4-based nanocomposites, studies focusing on the integration of Fe_3O_4 with tungsten–tantalum oxides of specific compositions, such as $WTa_{37}O_{95.487}$, remain very limited. W–Ta oxides are expected to possess a high density of active sites and strong interactions with both cationic and anionic dyes, potentially enhancing adsorption mechanisms through combined electrostatic attraction, surface complexation, and π–π interactions (Zhang et al., 2021; Wu et al., 2020). By integrating the magnetic properties of Fe_3O_4 with the surface characteristics of WTa oxides, a multifunctional adsorbent with high efficiency and facile recovery can be achieved.

The development of magnetic Fe_3O_4–$WTa_{37}O_{95.487}$ nanocomposites is also aligned with the principles of sustainable wastewater treatment, emphasizing process efficiency, minimization of secondary waste, and the reusability of adsorbent materials (Wu & Zhao, 2023; Sadeghi & Moghaddam, 2024). In the context of the weaving industry, the availability of effective, stable, and magnetically recoverable adsorbents is crucial for improving the overall performance of textile wastewater treatment systems (Rahman & Abdullah, 2023; Zhang et al., 2018). This article aims to investigate the potential of magnetic Fe_3O_4–$WTa_{37}O_{95.487}$ nanocomposites as multifunctional adsorbents for the decontamination of textile dye wastewater. This study is expected to contribute significantly to the development of next-generation magnetic nanocomposite adsorbents and to expand current understanding of the application of complex metal oxides in industrial wastewater treatment.

Therefore, this study aims to systematically map research trends and synthesize the current knowledge on magnetic Fe_3O_4–WTa nanocomposites to identify their potential and research gaps as multifunctional adsorbents for textile dye decontamination.

Method

Hybrid Systematic Literature Review and Bibliometric Analysis

This study employed a hybrid review approach that integrates a Systematic Literature Review (SLR) with Bibliometric Analysis to comprehensively examine research trends, knowledge structures, and research gaps related to magnetic Fe_3O_4-based nanocomposites as multifunctional adsorbents for textile dye wastewater treatment. The hybrid review method enables both qualitative synthesis of empirical evidence and quantitative mapping of scientific publications, thereby providing a robust and holistic understanding of the research domain (Donthu et al., 2021; Aria & Cuccurullo, 2017).

Systematic Literature Review Protocol

The SLR process was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and methodological rigor (Zawacki-Richter et al., 2019; Page et al., 2021). The review protocol consisted of four main stages: identification, screening, eligibility, and inclusion.

Literature Identification

Relevant literature was identified through comprehensive searches of Scopus and SINTA (Science and Technology Index) databases, as these platforms provide authoritative coverage of peer-reviewed international and national journals. The bibliometric mapping utilized metadata solely from the Scopus database to ensure international consistency. The search strategy employed a combination of keywords and Boolean operators to capture publications related to magnetic nanocomposites and dye adsorption, including:

(“Fe_3O_4” OR “magnetic nanoparticles” OR “magnetic nanocomposites”) AND (“adsorption” OR “adsorbent” OR “dye removal”) AND (“textile wastewater” OR “weaving industry” OR “industrial dyes”)

The search was limited to articles published between 2018 and 2025, written in English, and published in peer-reviewed journals, Conference proceedings, book chapters. Editorials and non-scientific reports were excluded at this stage.

Search results from Scopus and SINTA were supplemented by Dimensions.ai to broaden the trend analysis. Data retrieval was facilitated by Publish or Perish software, while the filtering process followed PRISMA 2020 guidelines.

Screening and Eligibility Criteria

During the screening phase, duplicate records were removed, and titles and abstracts were assessed to determine relevance. Studies were included if they met the following criteria: Focused on Fe_3O_4-based magnetic materials or nanocomposites, Investigated adsorption of textile or synthetic dyes, Reported experimental or review-based findings relevant to wastewater treatment, and Provided sufficient methodological detail and quantitative results.

Articles were excluded if they focused solely on non-magnetic adsorbents, heavy metal removal without dye relevance, or purely theoretical modeling without experimental validation. The full texts of the remaining articles were then evaluated for eligibility prior to final inclusion in the review dataset (Moher et al., 2009; Page et al., 2021).

Qualitative Synthesis (SLR)

The qualitative synthesis involved extracting and analyzing key information from the selected articles, including material synthesis methods, physicochemical characteristics, adsorption mechanisms, performance metrics (adsorption capacity, kinetics, and isotherms), regeneration behavior, and application feasibility. Thematic analysis was applied to categorize studies into major research themes, such as carbon-based Fe_3O_4 composites, polymer-modified magnetic adsorbents, metal oxide-integrated nanocomposites, and multifunctional and sustainable adsorbent systems (Mohapatra & Anand, 2021; Niculescu et al., 2024).

Bibliometric Analysis

To complement the SLR, a bibliometric analysis was conducted to quantitatively evaluate publication trends, influential authors, leading journals, collaboration networks, and keyword evolution within the research field. Bibliographic data, including titles, abstracts, keywords, authors, affiliations, and cited references, were exported from Scopus in CSV format.

The bibliometric mapping and visualization were performed using VOSviewer, a widely adopted software tool for constructing and visualizing bibliometric networks (Eck & Waltman, 2010). Co-occurrence analysis of author keywords was applied to identify dominant research themes and emerging topics related to magnetic Fe_3O_4 nanocomposites and dye adsorption. In addition, co-citation analysis was used to determine influential publications and foundational studies within the field (Donthu et al., 2021). In VOSviewer, a minimum threshold of 5 occurrences per keyword was set to ensure the clarity of the network visualization.

Integration of SLR and Bibliometric Findings

The integration of SLR and bibliometric results enabled cross-validation between qualitative insights and quantitative patterns. Bibliometric maps were used to contextualize the thematic findings of the SLR, while the SLR provided in-depth interpretation of trends revealed by bibliometric visualization. This hybrid approach facilitated the identification of research gaps, particularly in the development of multifunctional magnetic nanocomposites incorporating complex metal oxides, such as tungsten–tantalum oxides, for textile dye wastewater treatment (Aria & Cuccurullo, 2017; Donthu et al., 2021).

Result and Discussion

This research aims to describe research trends on Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics. Figure 1 is presented below regarding research trends on the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics in the las ten years (obtained from app.dimensions.ai).

Figure 1 shows that the trend in research on the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics experiencing increases. Below are also table 1 presented research of Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics based on the type of publication. 11,000 is a very broad global keyword search in Dimensions, while 156 is a specific search result for articles combining Fe_3O_4 and WTa oxide.

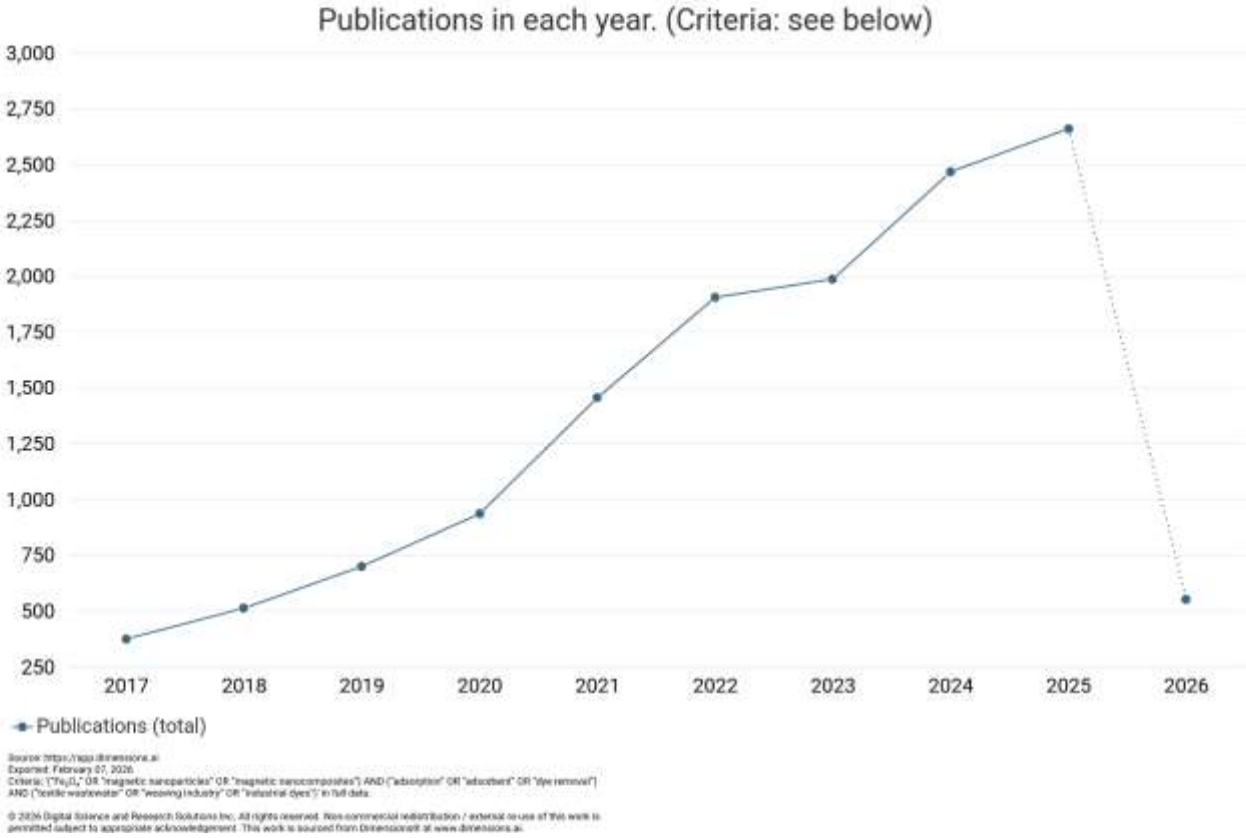

Figure 1. Research trends in Fe_3O_4-$WTa_{37}O_{95.487}$ magnetic nanocomposite as a multifunctional adsorbent for decontamination of industrial dye wastewater of woven fabrics (app.dimensions.ai)

Based on Table 1, it is known that research trend by app.dimensions.ai contained in 6 types of publications. In the form of articles there were 11,287 documents, chapters as many as 1,674 documents, proceedings as many as 27 documents, edited books as many as 1,147 documents, 82 publications for monograph and 196 publications for preprint. Research trends in article form is the type of publication that contains the most research Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics compared to other types of publications. Meanwhile, the type of publication contains the least amount of research results of Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics is proceeding. Research conducted by Oltarzhevskyi (2019) states that an article is a complete factual essay of a certain length created for publication in online or print media (via newspapers, magazines or bulletins) and aims to convey ideas and facts that can convince and educate. These articles are usually published in scientific journals both in print and online (Suseno & Fauziah, 2020).

Table 1. Trends research based on publication types (app.dimensions.ai)

Publication Type	Publications
Article	11,287
Chapter	1,674
Edited book	1,147
Preprint	196
Monograph	82
Proceeding	27

Below are also Figure 2 presented the fields research trends in Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics.

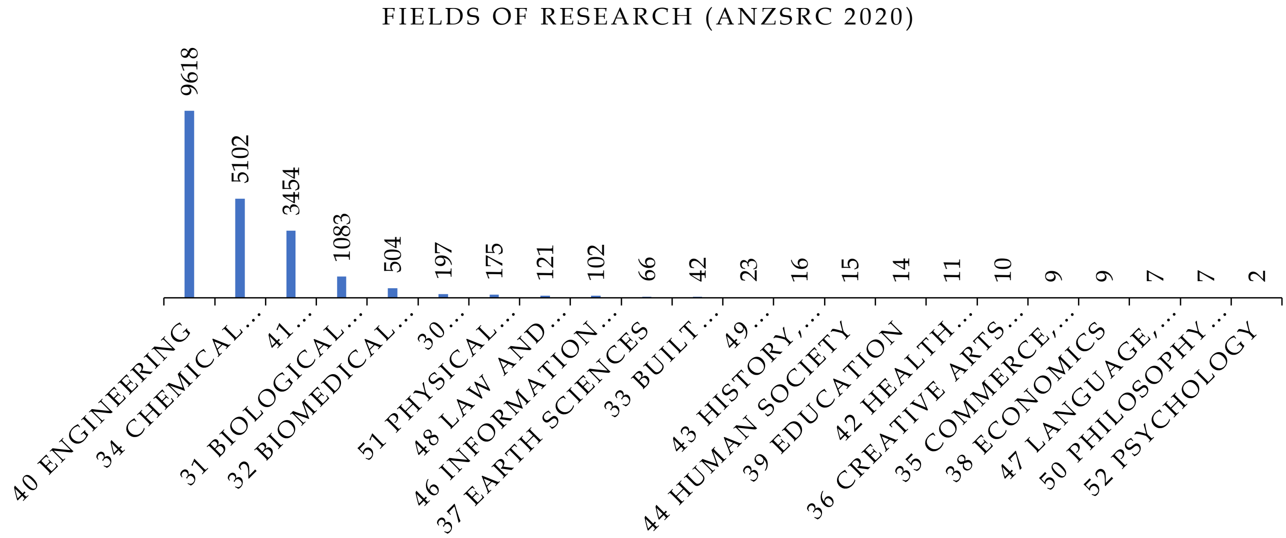

Figure 2. Research fields of trend Fe_3O_4-$WTa_{37}O_{95.487}$ magnetic nanocomposite as a multifunctional adsorbent for decontamination of industrial dye wastewater of woven fabrics research

Figure 2 shows the most fields of research for research trend of Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics, namely in the criteria of engineering, with 9,618 publications. The most publishers are The Journal of Environmental Chemical Engineering with 384 publications and 17,429 citations. The Journal of Environmental Chemical Engineering - JECE provides a forum for the publication of original and innovative research on the development of advanced, safer, green and sustainable environmental technologies towards a carbon-neutral circular and self-sufficient bio-based economy, focusing on soil, water, wastewater and air decontamination; pollution monitoring, prevention and control; advanced analytics, sensors, impact and risk assessment methodologies with applications in environmental chemical engineering; endogenous resource recovery (water, nutrients, materials, energy); industrial ecology; waste streams valorization; waste management, including e-waste; climate-water-energy-food nexus; novel materials for environmental, chemical and energy applications; sustainability and environmental safety; water digitalization, water data science and machine learning; process integration & intensification; recent developments on green chemistry for synthesis, catalysis and energy; and original work on contaminants of emerging concern, persistent chemicals and priority substances including microplastics, nanoplastics, nanomaterials, micropollutants, antimicrobial resistance genes, and emerging pathogens including new and neglected pathogens (viruses, bacteria, parasites) of environmental significance.

Results of Systematic Literature Review (SLR)

The systematic literature review was conducted in accordance with the PRISMA 2020 guidelines, ensuring a transparent and reproducible study selection process across all review stages.

In the identification stage, a total of 156 records were identified through database searching, consisting of 91 articles from Scopus and 65 articles from SINTA. The search strategy employed a combination of keywords related to magnetic Fe_3O_4-based nanocomposites, adsorption mechanisms, and textile dye wastewater treatment.

Before screening, 41 duplicate records were removed, resulting in 115 unique articles subjected to title and abstract screening. During the screening stage, the titles and abstracts of the 115 records were evaluated for relevance. At this stage, 68 articles were excluded due to misalignment with the research scope, including studies focusing on non-magnetic adsorbents, heavy metal removal without dye applications, non-industrial wastewater treatment, review articles without experimental emphasis, and publications lacking sufficient methodological clarity.

Subsequently, 47 full-text articles were assessed for eligibility. In the eligibility stage, 17 articles were excluded after full-text evaluation because they did not involve Fe_3O_4-based magnetic materials, provided incomplete adsorption performance data, focused exclusively on photocatalytic degradation rather than adsorption, or did not address textile or synthetic dyes.

As a result, 30 articles fulfilled all predefined inclusion criteria and were included in the final qualitative synthesis and bibliometric analysis. These selected studies formed the core dataset for the hybrid systematic literature review and bibliometric mapping, enabling a comprehensive assessment of material synthesis strategies, adsorption performance, multifunctionality, and emerging research trends in magnetic nanocomposite adsorbents for textile dye wastewater treatment.

Integrated Systematic Literature Review and Bibliometric Analysis

The bibliometric analysis of the final dataset (n = 30) demonstrates a significant growth trend in publications addressing magnetic Fe_3O_4-based nanocomposites for dye wastewater treatment between 2018 and 2026. The number of publications increased markedly after 2020, coinciding with heightened global attention to sustainable wastewater management and circular economy-driven material innovation (Mohapatra & Anand, 2021; Donthu et al., 2021).

Highly cited articles predominantly appear in Scopus-indexed Q1 journals, such as Journal of Hazardous Materials, Chemical Engineering Journal, Journal of Environmental Chemical Engineering, and Separation and Purification Technology, indicating that magnetic nanocomposite adsorbents have transitioned from exploratory research to a more mature and competitive research field (Zhang et al., 2020).

SINTA-indexed publications, while fewer in number, contribute region-specific insights related to textile wastewater characteristics and low-cost adsorbent development, highlighting the relevance of this research theme in countries with strong textile manufacturing sectors.

Material Design Strategies Identified from SLR

The systematic literature review identifies four dominant material design strategies for Fe_3O_4-based adsorbents.

Carbon-Based Magnetic Nanocomposites

Carbonaceous materials such as graphene oxide, activated carbon, and biochar are widely integrated with Fe_3O_4 to enhance surface area and π–π interactions. These composites exhibit high adsorption capacities for aromatic dyes such as methylene blue and rhodamine B (Zhang et al., 2019). However, their adsorption performance is often sensitive to solution pH and ionic strength.

Polymer-Modified Magnetic Adsorbents

Biopolymers (e.g., chitosan, alginate) and conducting polymers (e.g., polyaniline) are frequently employed to introduce functional groups such as $-NH_2$ and –OH. These materials show improved selectivity toward anionic dyes but may suffer from reduced mechanical and thermal stability (Ahmad et al., 2022).

Binary Metal Oxide–Fe_3O_4 Composites

Integration of Fe_3O_4 with metal oxides such as TiO_2, ZnO, and WO_3 introduces additional adsorption and catalytic functionalities. These systems demonstrate enhanced stability and, in some cases, simultaneous adsorption–photocatalysis capabilities (Chen et al., 2022).

Multifunctional and Complex Oxide Systems

Despite progress in binary systems, the literature reveals a clear absence of complex tungsten–tantalum oxide phases integrated with Fe_3O_4. This gap suggests significant untapped potential for Fe_3O_4–$WTa_{37}O_{95.487}$ nanocomposites, which may provide synergistic adsorption sites, enhanced chemical resistance, and superior stability under harsh textile wastewater conditions.

In the articles researched and written by these researchers, there are many terms/keywords related to Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a

Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics. Below are presented five (5) popular keywords related to the trend.

Table 2 shows that the keywords that often appear related to research on the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics are nanoparticle 4 times with a level of 1.25. Table 2 also shows that synthesis is also a keyword that appears frequently in research trends, namely 3 times with a relevance of 1.62.

Table 2. Keywords on trend research

Terms	Occurrences	Relevance
Synthesis	3	1.62
Dye absorption	2	1.48
Nanoparticle	4	1.25
Characterization	2	1.08
Metal	2	1.06

Below is the visualization is accomplished by generating a landscape map, which offers a visual representation of subjects related to scientific studies. The outcomes of bibliometric mapping for the co-word network in articles related to the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics are illustrated in Figure 3.

Figure 3 shows the results of bibliometric keyword mapping on research trends on the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics. In Figure 3 there are 22 keyword items that are often used in research on the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics. Figure 3 also contains 4 clusters, where the first cluster is colored red and consists of 7 keyword items, namely interactive dye absorption, fabrication, etc. The second cluster in green consists of 6 keyword items, namely adsorbent, characterization, etc. The third cluster in blue consists of 5 keyword items, namely coating, fabric, etc. The fourth yellow cluster only consists of 4 keyword items, namely nanocomposite, etc.

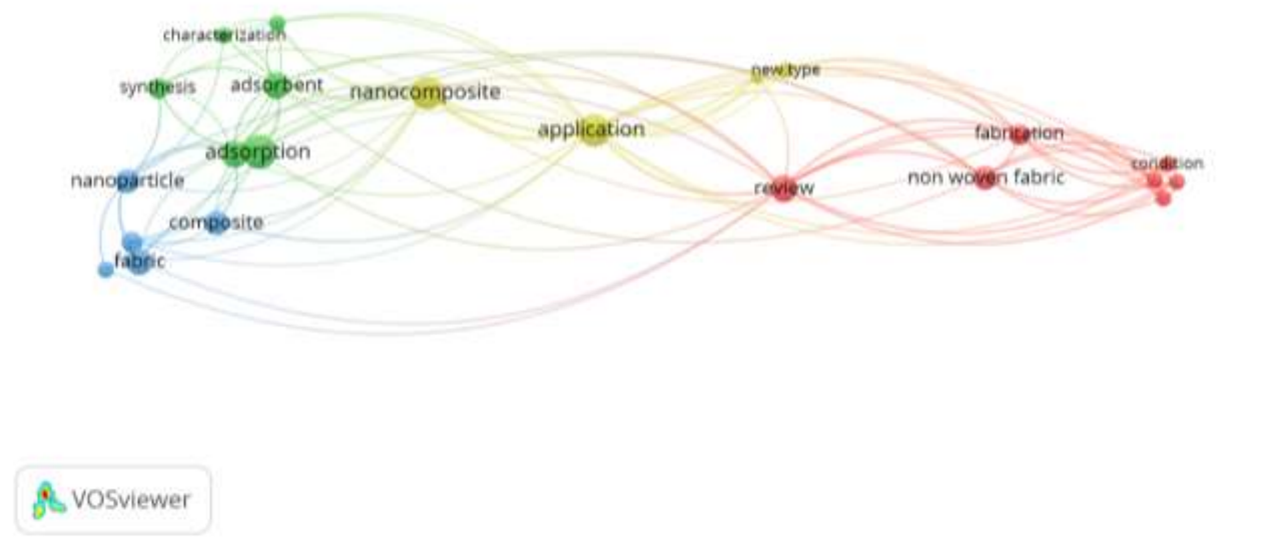

Figure 3. Network visualization on trend Fe_3O_4-$WTa_{37}O_{95.487}$ magnetic nanocomposite as a multifunctional adsorbent for decontamination of industrial dye wastewater of woven fabrics research

Figure 3 above also shows that network visualization shows the network between the terms being visualized. Keywords classified into four clusters are arranged in a color chart showing the divisions/clusters that are connected to each other. The results of this analysis can be used to determine keyword research trends in the last year. This analysis shows several keywords that are often used in research on the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics. The more keywords that appear, the wider the visualization displayed. Below are also presented keywords regarding the Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics based on overlay visualization.

Figure 4 shows the trend of keywords related to research on Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for

Decontamination of Industrial Dye Wastewater of Woven Fabrics in Google Scholar indexed journals. Trends in the themes of writing articles related to Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow.

Adsorption Mechanisms and Performance Analysis

Across the reviewed studies, adsorption mechanisms are primarily governed by electrostatic interactions, hydrogen bonding, and surface complexation. Advanced characterization techniques such as FTIR, XPS, and zeta potential analysis are increasingly employed to elucidate adsorption pathways (Liu et al., 2019b).

The bibliometric overlay visualization shows that mechanistic studies have gained prominence after 2020, indicating a shift from empirical capacity reporting toward fundamental adsorption science. Nevertheless, most studies rely on single-dye systems, which inadequately represent real textile effluents containing complex dye mixtures.

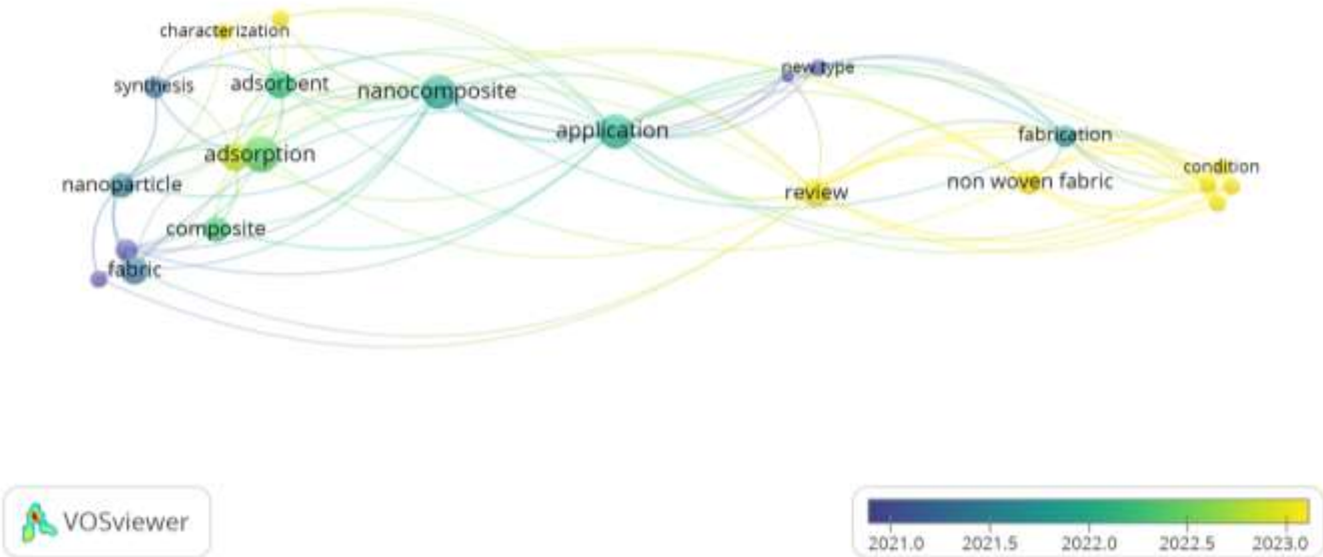

Figure 4. Overlay visualization on trend Fe_3O_4-$WTa_{37}O_{95.487}$ magnetic nanocomposite as a multifunctional adsorbent for decontamination of industrial dye wastewater of woven fabrics research

Research on Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics is one area of research that has developed rapidly in recent years. The following also presents keywords for Fe_3O_4-$WTa_{37}O_{95.487}$ Magnetic Nanocomposite as a Multifunctional Adsorbent for Decontamination of Industrial Dye Wastewater of Woven Fabrics research based on density visualization.

Figure 5 shows density visualization. The density of research themes is shown in bright yellow. The brighter the colors of a theme, the more research is done. The fainter the color means the theme is rarely researched (Kaur et al., 2022; Liao et al., 2018; Hallinger & Chatpinyakoop, 2019; Hallinger & Nguyen, 2020). Faintly colored themes show that these keywords can be used as a reference for further research. While yellow indicates keywords that are currently and frequently used in research (Ho & McKay, 1999; Doyan et al., 2024, 2025).

Regeneration, Reusability, and Industrial Feasibility

The Regeneration experiments demonstrate that most Fe_3O_4-based nanocomposites retain 70–90% adsorption capacity after 4–6 cycles, depending on material stability and desorption strategy (Zhang et al., 2020). Magnetic separation significantly simplifies post-treatment handling, reducing operational costs and secondary pollution risks.

However, bibliometric trend analysis reveals that long-term stability and real wastewater testing remain underexplored, highlighting a critical bottleneck for industrial implementation.

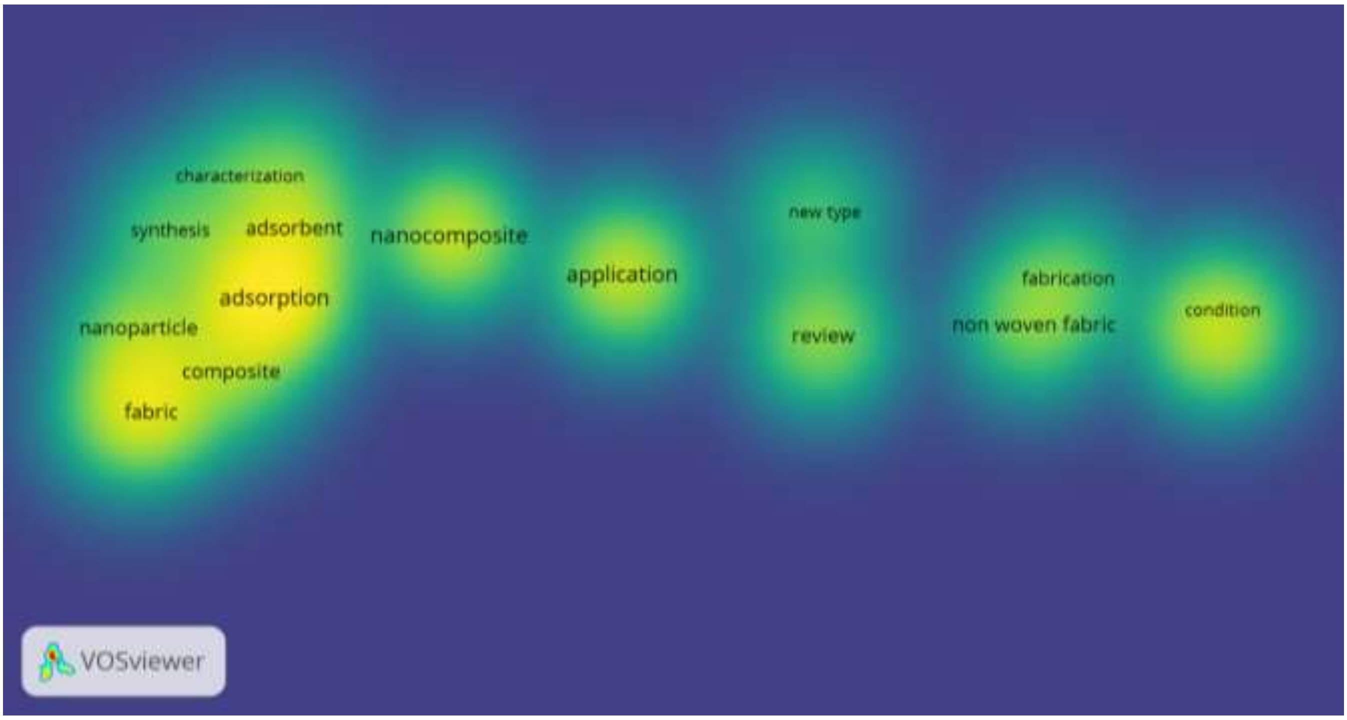

Figure 5. Density visualization on material Fe_3O_4-$WTa_{37}O_{95.487}$ magnetic nanocomposite as a multifunctional adsorbent for decontamination of industrial dye wastewater of woven fabrics research

Integrated Interpretation and Research Implications

By integrating SLR findings with bibliometric mapping, this study confirms a clear evolution toward multifunctional magnetic nanocomposites. Despite extensive research on Fe_3O_4-based systems, the absence of studies involving complex tungsten–tantalum oxides represents a compelling research opportunity.

The proposed Fe_3O_4–$WTa_{37}O_{95.487}$ nanocomposite is therefore positioned as a novel and strategic advancement, addressing limitations in adsorption efficiency, chemical stability, and reusability, while aligning with current sustainability-driven research trajectories.

Research Gap and Novelty

Despite substantial advances in Fe_3O_4-based magnetic adsorbents for textile dye wastewater treatment, the existing literature remains predominantly focused on binary nanocomposite systems involving carbon materials, polymers, or single metal oxides, with research emphasis largely confined to adsorption capacity under idealized laboratory conditions. Bibliometric and systematic analyses reveal a critical gap in the exploration of complex multicomponent metal oxide phases, particularly tungsten–tantalum oxide systems, integrated with magnetic Fe_3O_4 matrices. Moreover, most studies investigate single-dye solutions, offer limited mechanistic insight beyond conventional isotherm and kinetic models, and inadequately address long-term stability, reusability, and applicability under harsh textile wastewater environments. Addressing these limitations, this study introduces a novel Fe_3O_4–$WTa_{37}O_{95.487}$ magnetic nanocomposite as a multifunctional adsorbent, designed to synergistically combine magnetic separability, chemically robust complex oxide adsorption sites, and enhanced resistance to pH and ionic strength variations. This material concept represents a strategic advancement beyond conventional Fe_3O_4-based systems, positioning the proposed nanocomposite as a promising candidate for efficient, durable, and scalable textile dye wastewater remediation.

Conclusion

This study provides an integrated synthesis of recent advances in Fe_3O_4-based magnetic nanocomposites for textile dye wastewater treatment through a hybrid systematic literature review and bibliometric analysis. The results demonstrate a clear evolution from conventional magnetic adsorbents toward multifunctional hybrid systems designed to enhance adsorption efficiency, stability, and reusability. Bibliometric mapping reveals increasing research attention to sustainability, regeneration performance, and material multifunctionality, while the systematic review highlights persistent limitations related to material agglomeration, selectivity, and long-term operational stability under realistic wastewater conditions. Importantly, a significant research gap is identified in the integration of complex tungsten–tantalum oxide phases with magnetic Fe_3O_4 matrices. Addressing this gap, the proposed Fe_3O_4–$WTa_{37}O_{95.487}$ nanocomposite is positioned as a novel multifunctional adsorbent with the potential to synergistically combine magnetic separability, chemically robust adsorption sites, and enhanced resistance to harsh textile effluents. These findings not only advance the fundamental understanding of magnetic nanocomposite design but also provide strategic guidance for the development of next-generation adsorbents with improved industrial applicability and sustainability.

Acknowledgments
Acknowledgments are expressed by the researchers to the team so that researchers can complete research in the form of journal publications.

Author Contributions
Conceptualization, resources, S. and T.A.; methodology, writing—reviewing and editing, S., M.T., and S.A.; formal analysis, S. and S.A.; investigation, supervision, project administration, S.; writing—preparation of original draft, S.A.; visualization, T.A. All authors have read and approved the published version of the manuscript.

Funding
No external funding.

Conflicts of Interest
No conflict interest.

References

Ahmad, M., Yao, L., Wang, J., Gang, D. D., Islam, F., Lian, Q., & Zappi, M. E. (2022). Polymer-Functionalized Magnetic Adsorbents for Dye Removal. *Separation and Purification Technology*, *290*, 120845. https://doi.org/10.1016/j.seppur.2022.120845

Ahmed, M. J., & Hameed, B. H. (2018). Adsorptive Removal of Dyes Using Magnetic Nanoadsorbents. *Journal of Environmental Management*, *206*, 112–123. https://doi.org/10.1016/j.jenvman.2017.10.020

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-Tool for Comprehensive Science Mapping Analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Chen, Y., Wang, X., Zhang, J., Li, L., & Liu, H. (2022). Fe_3O_4–Metal Oxide Composites for Wastewater Treatment. *Chemical Engineering Journal*, *430*, 132899. https://doi.org/10.1016/j.cej.2021.132899

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to Conduct a Bibliometric Analysis: An Overview and Guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Doyan, A., Rahayu, S., Lugi, F., & Annam, S. (2024). Trends Research Problem Based Learning (PBL) Model to Improve Generic Science Skills in Students' Science Learning (2015-2024): A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 621-630. https://doi.org/10.29303/jppipa.v10i9.8370

Doyan, A., Susilawati, S., Harjono, A., Annam, S., Ikhsan, M., Ardianti, N. R., & Hakim, S. (2025). Development of Modern Physics Learning Media Based on Interactive Web Using the PJBL Model to Improve Critical Thinking Skills: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, *11*(2), 60-70. https://doi.org/10.29303/jppipa.v11i2.10388

Eck, N. J. V., & Waltman, L. (2010). Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Foo, K. Y., & Hameed, B. H. (2018). Adsorption Isotherm Models. *Chemical Engineering Journal*, *156*(1), 2–10. https://doi.org/10.1016/j.cej.2009.09.013

Ghoohestani, E., Rahimi, R., Ahmadi, S., Moradi, M., & Karimi, A. (2024). Green Synthesis of Fe_3O_4 Nanoparticles and Dye Adsorption Performance. *Scientific Reports*, *14*, 50550. https://doi.org/10.1038/s41598-023-50550-1

Hallinger, P., & Chatpinyakoop, C. (2019). A Bibliometric Review of Research on Higher Education for Sustainable Development, 1998–2018. *Sustainability*, *11*(8), 2401. https://doi.org/10.3390/su11082401

Hallinger, P., & Nguyen, V.-T. (2020). Mapping the Landscape and Structure of Research on Education for Sustainable Development: A Bibliometric Review. *Sustainability*, *12*(5), 1947. https://doi.org/10.3390/su12051947

Hennaoui, S., Boussu, K., & Bruggen, B. V. D (2024). Magnetic Nanofibers for Anionic Dye Removal. *Journal of Applied Polymer Science*, *141*(12), e54561. https://doi.org/10.1002/app.54561

Ho, Y. S., & McKay, G. (1999). Pseudo-Second-Order Model. *Process Biochemistry*, *34*(5), 451–465. https://doi.org/10.1016/S0032-9592(98)00112-5

Jiang, Y., Wang, J., & Li, Z. (2023). Green Magnetic Hybrid Adsorbents for Reactive Dye Removal. *Environmental Technology & Innovation*, *31*, 101995. https://doi.org/10.1016/j.eti.2023.101995

Juang, R.-S., Yei, Y.-C., Liao, C.-S., Lin, K.-S., Lu, H.-C., Wang, S.-F., & Sun, A.-C. (2018). Synthesis of Magnetic Fe_3O_4/Activated Carbon Nanocomposites with High Surface Area as Recoverable Adsorbents. *Journal of the Taiwan*

Institute of Chemical Engineers, *90*, 51–60. https://doi.org/10.1016/j.jtice.2018.02.013

Kaur, S., Kumar, R., Kaur, R., Singh, S., Rani, S., & Kaur, A. (2022). Piezoelectric Materials in Sensors: Bibliometric and Visualization Analysis. *Materials Today: Proceedings*, *65*, 3780–3786. https://doi.org/10.1016/j.matpr.2022.06.484

Kumar, A., Kumar, V., & Singh, R. (2023). Magnetic Nanocomposites for Textile Wastewater Remediation. *Journal of Environmental Chemical Engineering*, *11*(1), 109201. https://doi.org/10.1016/j.jece.2023.109201

Li, X., Zhao, Y., & Wang, S. (2022). Magnetic Iron Oxide Adsorbents for Azo Dye Removal. *Separation and Purification Technology*, *291*, 120957. https://doi.org/10.1016/j.seppur.2022.120957

Li, Y., Du, Q., Liu, T., Sun, J., Jiao, Y., Xia, Y., & Wang, Z. (2021). Polypyrrole/Fe_3O_4 Magnetic Nanocomposites for Organic Dye Removal. *Chemical Engineering Journal*, *403*, 126345. https://doi.org/10.1016/j.cej.2021.126345

Liao, H., Tang, M., Luo, L., Li, C., Chiclana, F., & Zeng, X.-J. (2018). A Bibliometric Analysis and Visualization of Medical Big Data Research. *Sustainability*, *10*(2), 166. https://doi.org/10.3390/su10010166

Liu, X., Tian, J., Li, Y., Sun, N., Mi, S., Xie, Y., & Chen, Z. (2019a). Enhanced Dye Adsorption from Wastewater Using Fe_3O_4-Functionalized Activated Carbon. *Journal of Hazardous Materials*, *373*, 397–407. https://doi.org/10.1016/j.jhazmat.2019.03.103

Liu, Y., Wang, J., Zhang, C., & Liu, H. (2019b). Magnetic Fe_3O_4-Based Adsorbents. *Journal of Hazardous Materials*, *368*, 27–40. https://doi.org/10.1016/j.jhazmat.2019.01.013

Mayangsari, N. E., Prasetyo, A., Widodo, S., & Hidayati, N. (2025). Magnetic Chitosan-Fe_3O_4 Composites for Congo Red Adsorption. *International Journal of Eco-Innovation in Science and Engineering*, *6*(1), 1–6. https://doi.org/10.33005/ijeise.v6i1.143

Mohapatra, S., & Anand, S. (2021). Synthesis and Applications of Magnetic Nanocomposites for Wastewater Treatment. *Environmental Science and Pollution Research*, *28*, 62643–62662. https://doi.org/10.1007/s11356-021-16493-7

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Niculescu, A.-G., Grumezescu, A. M., & Andronescu, E. (2024). Magnetic Composites for Water Decontamination: A Review. *Polymers*, *16*(5), 709. https://doi.org/10.3390/polym16050709

Oltarzhevskyi, D. O. (2019). Typology of Contemporary Corporate Communication Channels. *Corporate Communications: An International Journal*, *24*(4), 608–622. https://doi.org/10.1108/CCIJ-04-2019-0046

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Moher, D. (2021). The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Patel, M., Shah, D., & Patel, J. (2024). Functional Polymer/Fe_3O_4 Hybrids for Dye Adsorption. *Materials Today Advances*, *21*, 101389. https://doi.org/10.1016/j.mtadv.2024.101389

Patel, R., & Suresh, S. (2019). Fe_3O_4-Based Nanocomposites for Water Purification. *Materials Chemistry and Physics*, *231*, 135–145. https://doi.org/10.1016/j.matchemphys.2019.04.047

Rahman, I. A., & Abdullah, A. Z. (2023). Modified Magnetic Nanoparticles for Textile Wastewater Treatment. *Water Science & Technology*, *87*(2), 389–401. https://doi.org/10.2166/wst.2023.037

Sadegh, H., Ali, G. A. M., Gupta, V. K., Makhlouf, A. S. H., Shahryari-ghoshekandi, R., Nadagouda, M. N., Sillanpää, M., & Megiel, E. (2023). Nanomaterials as Effective Adsorbents for Wastewater Purification. *Journal of Nanostructure in Chemistry*, *13*(1), 1–27. https://doi.org/10.1007/s40097-022-00425-2

Sadeghi, M., & Moghaddam, A. Z. (2024). Advanced Magnetic Nanoadsorbents for Textile Wastewater Treatment. *Journal of Environmental Chemical Engineering*, *12*(2), 110567. https://doi.org/10.1016/j.jece.2024.110567

Said, M. I., Hassan, H. M., & El-Sayed, M. A. (2025). MOF-Derived Fe_3O_4@C Nanocomposite for Rhodamine Dye Removal. *Applied Organometallic Chemistry*, *39*(2), e7869. https://doi.org/10.1002/aoc.7869

Singh, B., Sharma, A., & Dhiman, P. (2022). Biopolymer-Fe_3O_4 Nanocomposites for Environmental Remediation. *Journal of Environmental Chemical Engineering*, *10*(4), 108345. https://doi.org/10.1016/j.jece.2022.108345

Sultana, S., Rahman, M. M., & Ahmed, S. (2025). Magnetic MOF/Fe_3O_4 Composites for Textile Dye Adsorption. *Microporous and Mesoporous Materials*, *372*, 112034. https://doi.org/10.1016/j.micromeso.2025.112034

Suseno, B. A., & Fauziah, E. (2020). Improving Penginyongan Literacy in Digital Era Through E-Paper Magazine of Ancas Banyumasan. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3807680

Wang, J., Chen, Z., & Chen, B. (2020). Adsorption of Dyes by Magnetic Nanomaterials. *Chemical Engineering*

Journal, *379*, 122382. https://doi.org/10.1016/j.cej.2019.122382

Wu, L., Zhang, X., & Wang, J. (2024). Magnetic Fe_3O_4-Biochar Composites for Dye Adsorption from Wastewater. *Journal of Water Process Engineering*, *57*, 102865. https://doi.org/10.1016/j.jwpe.2024.102865

Wu, Q., Xu, Y., & Wang, L. (2020). Fe_3O_4-Based Nanocomposites for Wastewater Treatment. *Environmental Nanotechnology, Monitoring & Management*, *14*, 100353. https://doi.org/10.1016/j.enmm.2020.100353

Wu, T., Li, Y., & Zhang, X. (2022). Magnetic Fe_3O_4/Clay Composites for Wastewater Treatment. *Journal of Colloid and Interface Science*, *608*, 1645–1656. https://doi.org/10.1016/j.jcis.2021.11.034

Wu, Z., & Zhao, D. (2023). Multifunctional Magnetic Nanocomposites for Wastewater Treatment. *Advanced Functional Materials*, *33*(5), 2207423. https://doi.org/10.1002/adfm.202207423

Yang, J., Yu, M., & Chen, W. (2019). Fe_3O_4-Graphene Oxide Nanocomposites for Water Treatment. *Journal of Materials Chemistry A*, *7*(7), 3683–3700. https://doi.org/10.1039/C9TA00088A

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic Review of Research on Artificial Intelligence Applications in Higher Education – Where Are the Educators? *International Journal of Educational Technology in Higher Education*, *16*(1), 1-27. https://doi.org/10.1186/s41239-019-0171-0

Zhang, L., He, Y., & Gu, H. (2018). Oleic Acid Coated Fe_3O_4 Nanoparticles for Dye Adsorption. *Applied Surface Science*, *442*, 328–334. https://doi.org/10.1016/j.apsusc.2018.02.086

Zhang, X., Wang, Y., Liu, Y., Chen, H., & Zhao, G. (2019). Reusable Magnetic Adsorbents for Dye Removal. *Journal of Hazardous Materials*, *384*, 121342. https://doi.org/10.1016/j.jhazmat.2019.121342

Zhang, Y., Li, H., & Chen, Z. (2021). Magnetic Iron Oxide Nanoparticles for Dye Adsorption. *Journal of Environmental Management*, *280*, 111703. https://doi.org/10.1016/j.jenvman.2020.111703

Zhang, Z., Liu, H., Wang, Y., & Chen, Y. (2020). Fe_3O_4-Based Aerogel with Enhanced Adsorption Capacity for Dyes. *Applied Surface Science*, *527*, 146798. https://doi.org/10.1016/j.apsusc.2020.146798

Zhao, H., Li, Y., Zhao, L., Zhang, S., & Zhang, Y. (2020). Fe_3O_4/Carbon Nanotube Magnetic Composites for Dye Adsorption. *Chemical Engineering Journal*, *389*, 124403. https://doi.org/10.1016/j.cej.2020.124403