J Water Environ Nanotechnol 2026, 11(3): 395-404
10.22090/jwent.2025.2077526.2007

RESEARCH PAPER

Photocatalytic Removal of Dye Pollutants From Water Using Co_3O_4 Nanoparticles Synthesized From Diplocyclos Palmatus Leaf Extract

Gurusamy Thangam Parethe [1], ***Gopalan Subashini*** [2]*

[1] Department of Chemistry, VSB College of Engineering & Technical campus, Coimbatore- 642109, India
[2] Department of Chemistry, PSGR Krishnammal College for Women, Coimbatore-641032, India

*Corresponding Author(s)
Email:
gsubashini2010@gmail.com

Article History:

Received: 2025-11-11
Revised: 2026-01-20
Accepted: 2026-01-30

How to cite this article
Parethe GT, Subashini G. Photocatalytic Removal of Dye Pollutants from Water Using Co_3O_4 Nanoparticles Synthesized from Diplocyclos Palmatus Leaf Extract. J Water Environ Nanotechnol 2026, 11(3): 395-404, DOI: 10.22090/jwent.2025.2077526.2007

HIGHLIGHTS

- Recent advancements in the removal of organic pollutants from water surfaces address a critical environmental concern.
- The efficiency of dye degradation is influenced by catalyst dosage, reaction time, pH of the medium, surface area, and particle size.
- Co_3O_4 nanoparticles synthesized using D. palmatus leaf extract demonstrated an advanced oxidation process capable of degrading high-concentration pollutants in an eco-friendly manner.
- Photocatalytic dye degradation mechanisms were explored for their potential in effective wastewater remediation.

ABSTRACT

Cobalt oxide nanoparticles (Co_3O_4-NPs) were synthesised via a green route using ***Diplocyclos palmatus*** leaf extract and evaluated for photocatalytic dye degradation. Structural analysis by XRD confirmed the cubic phase of Co_3O_4 with an average crystallite size of 23 nm. SEM and EDX revealed irregularly spherical nanoparticles composed of cobalt and oxygen. The photocatalytic activity of Co_3O_4-NPs was assessed against methylene blue (MB) dye under sunlight irradiation. Key operational factors such as dye concentration, pH, catalyst dosage, and reusability were systematically investigated. The nanoparticles demonstrated excellent photocatalytic activity, achieving 89% degradation of MB within 120 minutes. Prolonged irradiation enhanced the degradation efficiency, with 91% removal observed at pH 9 for the same duration, confirming that alkaline conditions favour the process. Conversely, higher dye concentrations resulted in reduced degradation efficiency. At an optimised dosage of 0.013 g of catalyst, 90% degradation was achieved, highlighting the role of catalyst loading in the process. Upon recycling, the catalyst retained substantial activity, degrading 85% of the dye in the first cycle. Overall, the Co_3O_4 nanoparticles displayed reliable and visible-light-driven photocatalytic activity, underscoring their potential as promising materials for the removal of organic pollutants in wastewater treatment applications.

KEYWORDS:

Photocatalytic degradation; Cobalt oxide nanoparticles (Co_3O_4-NPs); Diplocyclos palmatus; Visible-light photocatalyst; Methylene blue degradation

©2026 The Author(s). Published by the Iranian Environmental Mutagen Society. This work is licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

INTRODUCTION

Water pollution has intensified due to population growth and industrial expansion, leading to both water scarcity and deteriorating water quality. Addressing this challenge is critical for safeguarding human health, ecosystems, and drinking water safety [1, 2]. Since water is essential for all forms of life, ensuring its quality is vital not only for humans but also for other living organisms. A primary contributor to water contamination is the persistent discharge of non-recyclable industrial pollutants [3], with synthetic dyes representing a major environmental concern. These dyes impede photosynthesis and pose serious health risks, including skin irritation, allergic reactions, and even cancer [4, 5].

Textile industries alone release 10–15% of dyes during the dyeing process, contributing significantly to water pollution. Purifying textile waste effluents, especially dyes, is vital for both human health and the environment. Textile dyes can be purified using a variety of processes, including biological, filtration, adsorption, sedimentation, ion exchange, UV treatment, and ozonation [6]. However, many of them are expensive, scarce, and useless in certain instances. At the moment, scientists are drawn to photodegradation as a potential method for these uses due to its high accessibility and efficiency. Conventional treatment methods such as flocculation, activated carbon adsorption, and UV-based degradation often face limitations, including high operational costs, low efficiency, and secondary pollution, rendering them environmentally unsustainable [7]. Recent developments in nanotechnology offer promising alternatives for wastewater remediation [8]. Nanoparticles possess unique properties—small size, large surface area, and tunable morphology—that make them highly effective in photocatalytic applications, enabling complete degradation of organic pollutants [9].

Photocatalytic degradation relies on sunlight-activated catalysts to produce reactive hydroxyl (•OH) radicals, which oxidize contaminants into harmless end products such as CO_2, H_2O, and inorganic ions [10, 11]. This approach is environmentally friendly, cost-effective, and more efficient than traditional techniques [12]. Among nanomaterials, metal oxide nanoparticles are particularly attractive due to their size-dependent physicochemical properties and broad applications in medicine, sensors, solar energy, and environmental technologies. Methylene blue (MB) [3, 7-bis (dimethyl amino) phenothiazine chloride tetra methylthionine chloride] is a synthetic dye widely used in textiles, paper, silk, and wool, as well as in medicine, food, and cosmetics [13]. Untreated MB discharge poses serious health risks, including cyanosis, Heinz body formation, jaundice, and vomiting [14]. Therefore, effective and sustainable removal methods are essential [15].

Despite extensive reports on green-synthesized photocatalysts for dye degradation, most studies have focused on TiO_2, ZnO, and CuO nanoparticles, while green routes for Co_3O_4 nanoparticles remain comparatively underexplored [16–18]. Moreover, many existing approaches rely on artificial UV or visible light sources and provide limited insight into catalyst stability and reusability, restricting their practical implementation [19]. The role of plant-derived phytochemicals in tailoring Co_3O_4 nanoparticle morphology and enhancing sunlight-driven photocatalytic activity has also received minimal attention. In this context, the present work addresses these gaps by employing Diplocyclos palmatus leaf extract for the green synthesis of Co_3O_4 nanoparticles via a simple co-precipitation method and systematically evaluating their sunlight-assisted degradation of methylene blue. This study demonstrates a cost-effective, sustainable, and scalable photocatalytic system with improved efficiency and reusability for environmental remediation.

In this study, Co_3O_4 nanoparticles were synthesized using leaf extracts of Diplocyclos palmatus (L.) C. Jeffrey via the co-precipitation method [20]. Co_3O_4 was selected for its favorable physicochemical properties, including a high band gap that enhances photocatalytic activity. The nanoparticles were characterized using UV–visible spectroscopy, XRD, SEM, and EDX to determine their structure, morphology, and composition. Their photocatalytic performance for MB degradation under sunlight was evaluated, examining key factors such as irradiation time, pH, catalyst dosage, dye concentration, and reusability.

This study presents a green, cost-effective approach for dye removal, demonstrating the potential of Co_3O_4 nanoparticles to overcome the limitations of conventional wastewater treatment and offering valuable insights into optimizing photocatalytic processes for environmental remediation.

MATERIAL AND METHODS

Preparation of leaf extracts

The leaves were first washed thoroughly with tap water, followed by rinsing with double-distilled water, and then air-dried at room temperature for 20 days. Once dried, the leaves were ground into a fine powder. For extract preparation, 10 g of the leaf powder was placed in a glass beaker, and 200 mL of distilled water was added. The mixture was stirred continuously on a magnetic stirrer for 3 hours. After stirring, the solution was filtered, collected, and stored for subsequent use in nanoparticle synthesis.

Synthesis of Co_3O_4 Nanoparticles

The mixture was stirred for 5 minutes, after which NaOH solution was added dropwise until the desired pH was reached, accompanied by an observable colour change. The resulting mixture was then centrifuged at 5000 rpm for 10 minutes. The supernatant was discarded, and the pellet containing the Co_3O_4 nanoparticles was collected and washed with distilled water to

remove impurities. The purified precipitate was dried in a hot air oven at 50°C for 3 hours. The resulting fine powder was subsequently used for further characterisation.

Sunlight-driven photocatalytic degradation of MB

All experiments were carried out at Government Arts College, Coimbatore, Tamil Nadu, India (GPS coordinates: 11.0168° N, 76.9558° E) during the summer (pre-monsoon) season in May. The photocatalytic activity was evaluated under natural sunlight, and the effects of irradiation time, pH, catalyst dosage, and dye concentration were systematically studied.

Photodegradation of methylene blue dye using Co_3O_4 nanoparticles

The photocatalytic degradation of methylene blue (MB) dye was evaluated under sunlight using Co_3O_4 nanoparticles. MB solutions of 10, 20, 30, and 40 ppm were prepared by dissolving the dye in 250 mL of distilled water and adjusting the volume in a standard flask. For each experiment, 100 mL of MB solution was placed in a beaker, and 0.005 g of Co_3O_4 nanoparticles was added. The mixtures were kept in the dark for 1 hour to achieve adsorption–desorption equilibrium before exposure to sunlight.

The degradation of MB was monitored at various time intervals using a UV–visible spectrophotometer. The study investigated the influence of several parameters on photocatalytic efficiency, including irradiation time, dye concentration, pH, catalyst dosage, and reusability of the catalyst. Different catalyst amounts were tested to evaluate the effect of dosage. The effect of pH was studied using solutions with pH values of 5, 7, and 9, prepared by adding 1 M HCl and 1 M NaOH to distilled water prior to dye dissolution. Time-dependent degradation was monitored at intervals of 5, 15, 30, 45, 60, 75, 90, 105, and 120 minutes, and dye concentrations of 10, 20, 30, and 40 ppm were compared to assess their impact on photocatalytic activity.

Dye degradation UV-visible analysis

The photocatalytic degradation of methylene blue (MB) dye was monitored using a UV–visible spectrophotometer. The percentage of dye degradation was calculated using the following formula:

$$\text{Degradation rate (\%)} = (C_0 - C / C_0) \times 100 \quad (1)$$

$$\text{Degradation rate (\%)} = (A_0 - A / A_0) \times 100 \quad (2)$$

Where (C) represents the dye concentration at a given time, (C_0) is the initial dye concentration, (A) is the absorbance of the dye after sunlight irradiation, and (A_0) is the initial absorbance before irradiation.

CHARACTERIZATION

The Co_3O_4 nanoparticles synthesised from the fruit extracts of *D. palmatus* were characterised using UV–visible spectroscopy, FTIR, X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray (EDX) analysis and particle size analysis. UV–visible spectroscopy was employed to study the absorption spectra of the nanoparticles. SEM (Carl Zeiss, USA, and Model Sigma with Gemini Column) was used to examine the surface morphology and particle size. EDX analysis provided information on the elemental composition, while XRD was used to determine the phase and crystalline structure of the synthesised Co_3O_4 nanoparticles.

RESULT AND DISCUSSIONS

UV-visible analysis

Typically, the UV–visible spectrum of cobalt oxide nanoparticles exhibits a strong absorption in the visible region between 200 and 350 nm. The Co_3O_4 nanoparticles synthesised from the leaf extracts of D. palmatus displayed a prominent absorption peak at 256 nm [21], corresponding to the characteristic presence of cobalt oxide, as illustrated in Fig. 1.

Fourier Transform Infrared Spectroscopy (FTIR)

FT-IR spectroscopy has been used to determine the surface functional groups, as well as their interaction with the Co_3O_4-NPs. The spectrum was examined for the biomolecules responsible for the stabilization of Cobalt oxide nanoparticles.

Fig. 2 shows the FT-IR spectra of Co_3O_4-NPs that exhibit strong peaks at the wavelength of 2916 cm^{-1} corresponding to the O-H stretching vibration of phenolic compounds. The peak at 1614 cm^{-1} is due to C=C stretching. The peak at 1411 cm^{-1} is due to S=O stretching. The absorption bands at 563 cm^{-1}

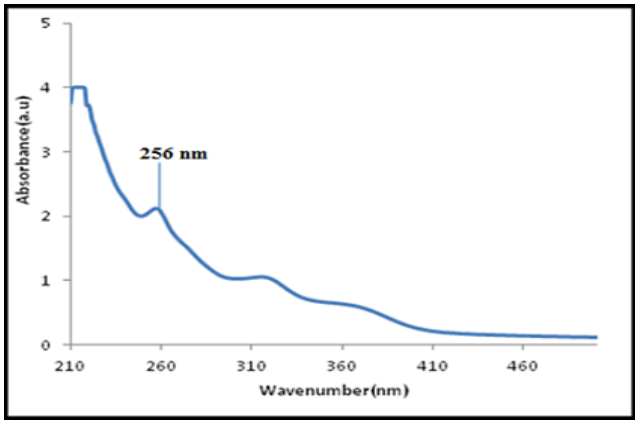

Fig. 1. UV–Visible absorption spectrum of Co_3O_4 nanoparticles synthesized using *D. palmatus* leaf extract, confirming the formation of cobalt oxide nanoparticles.

J Water Environ Nanotechnol, 2026, 11(3): 395-404
10.22090/jwent.2025.2077526.2007

correspond to the stretching vibration of the Co-O bond [22].

XRD pattern analysis

X-ray diffraction (XRD) analysis was performed to confirm the successful synthesis of Co_3O_4 nanoparticles and to investigate their crystalline structure. The XRD pattern exhibited major peaks at 2θ values of 19.1°, 31.3°, 38.8°, and 55.8°, corresponding to the (111), (220), (222), and (422) lattice planes, respectively, as shown in Fig. 3. These peaks are in good agreement with the standard XRD data for cubic-phase Co_3O_4 nanoparticles (JCPDS No. 42-1467) [23]. The average particle size was estimated using the Debye–Scherer equation:

$$D = K\lambda / \beta\cos\theta \quad (3)$$

Where (D) is the particle size, (lambda) is the X-ray wavelength (Cu Kα radiation, 1.5418 Å), (K) is the shape factor (≈0.9), (beta) is the full width at half maximum (FWHM) of the main diffraction peak, and (\theta) is the Bragg angle. Using this method, the average particle size of the synthesized Co_3O_4 nanoparticles was found to be 23 nm.

Particle Size Analysis

The distribution of the particle sizes has been studied using dynamic light scattering (DLS). The average particle size was found to be around 70 nm.

SEM & EDX analysis

The morphology of Co_3O_4 nanoparticles was examined using scanning electron microscopy (SEM). The SEM images revealed that the nanoparticles are irregularly spherical in shape, as shown in Fig. 5(a, b). The elemental composition of the synthesized Co_3O_4 nanoparticles, obtained from the leaf extract of D. palmatus, was analyzed using energy-dispersive X-ray (EDX) spectroscopy. The EDX spectrum (Fig. 5c) displayed distinct peaks corresponding to cobalt and oxygen, confirming the formation of cobalt oxide. Quantitative analysis indicated that the nanoparticles contain approximately 27 atomic percent

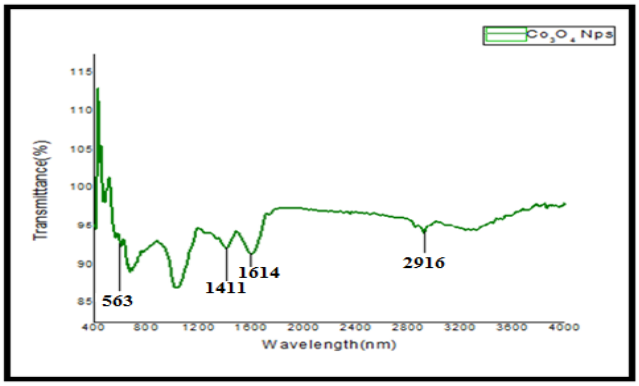

Fig. 2. FT-IR spectra of biosynthesized Co_3O_4-NPs showing characteristic Co–O vibrations and residual phytochemical functional groups from the plant extract.

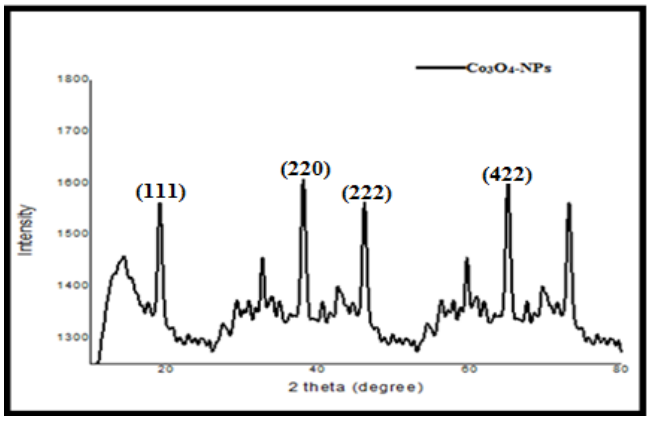

Fig. 3. XRD pattern of Co_3O_4-NPs confirming the cubic spinel structure and phase purity of the synthesized nanoparticles.

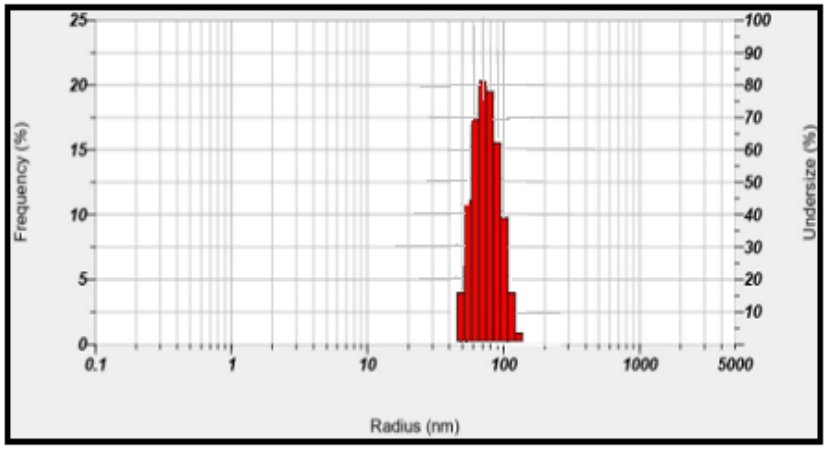

Fig. 4. Particle size distribution of Co_3O_4-NPs indicating the average particle size and size uniformity.

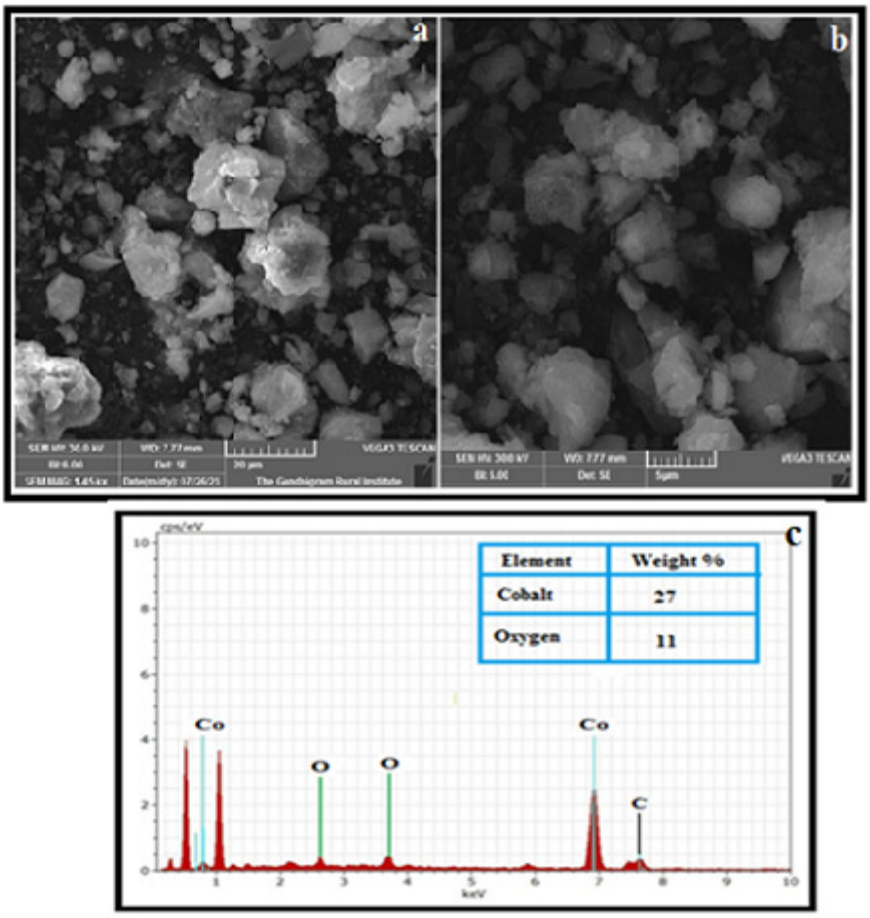

Fig. 5. SEM micrographs and EDX spectra of Co_3O_4-NPs showing surface morphology and elemental composition.

of cobalt and 11 atomic percent of oxygen, consistent with the composition of Co_3O_4 [24].

Mechanism for photodegradation of methylene dye using Co_3O_4 nanoparticles

The photocatalytic degradation of dyes involves several key stages, including electron–hole pair formation, adsorption–desorption processes, and subsequent chemical reactions [25]. The process can be summarized as: (1) adsorption of MB dye molecules onto the catalyst surface, (2) absorption of incident light, and (3) generation of charge-transfer reactions through oxidation and reduction processes [26].

Upon sunlight irradiation, electrons (e^-) in the Co_3O_4 photocatalyst are excited from the valence band (VB) to the conduction band (CB), leaving behind positive holes (h^+) in the VB. The photogenerated holes can directly oxidize dye molecules or react with water to produce highly reactive hydroxyl radicals (•OH). Simultaneously, electrons in the CB react with dissolved oxygen molecules to generate superoxide anions (O_2^{-}•). These reactive species work synergistically to degrade the dye molecules into harmless end products, such as CO_2, H_2O, and inorganic ions.

$$Co_3O_4\text{-NPs} + h\nu \rightarrow Co_3O_4\text{-NPs}\ (h^+ + e^-) \quad (4)$$

$$h^+ + \text{MB Dye} \rightarrow \text{oxidation of dye molecules} \quad (5)$$

$$h^+ + OH^- / H_2O \rightarrow {}^{\bullet}OH \quad (6)$$

$$e^- + O_2 \rightarrow {}^{\bullet}O_2^- \quad (7)$$

$$^{\bullet}OH + {}^{\bullet}O_2^- + \text{MB dye} \rightarrow \text{degradable / less-toxic} \quad (8)$$

The energy difference between the oxidation and reduction processes is determined by the material's band gap. The band gap of a metal oxide plays a crucial role in its photocatalytic activity, with narrower band gaps generally exhibiting higher efficiency for dye degradation [27].

J Water Environ Nanotechnol, 2026, 11(3): 395-404
10.22090/jwent.2025.2077526.2007

Effect of dye concentration of Co_3O_4 NPs on the Photocatalytic Degradation

The effect of initial dye concentration on methylene blue (MB) degradation was investigated using concentrations ranging from 10 to 40 mg/L. The photographs illustrate the colour change of MB solutions at 10, 20, 30, and 40 mg/L after 120 minutes of photocatalytic treatment. Initially, the 10 mg/L solution exhibited a lighter hue, which intensified with increasing dye concentration. The results indicate that higher dye concentrations lead to a slower degradation rate, demonstrating an inverse relationship between dye concentration and photocatalytic efficiency.

The UV–visible spectra indicate that increasing the dye concentration reduces the photocatalytic degradation of methylene blue (MB). According to Beer–Lambert's law, higher dye concentrations decrease the penetration of photons into the solution, resulting in lower photon absorption and reduced photocatalytic efficiency [28]. Consequently, the percentage of MB degradation decreases with increasing dye concentration. After 120 minutes of sunlight irradiation, the degradation efficiencies for 10, 20, 30, and 40 mg/L MB solutions were 89%, 65%, 49%, and 35%, respectively, as illustrated in Fig. 6.

Effect of Time of Co_3O_4 NPs on the Photocatalytic Degradation

Co_3O_4 nanoparticles were used to degrade a 10ppm methylene blue (MB) solution under sunlight. The absorption peak of MB dye at 665 nm gradually decreased over time, indicating photocatalytic degradation. Visual observation through photographic images shows the progressive color change of the dye at different time intervals: 0, 5, 15, 30, 45, 60, 75, 90, 105, and 120 minutes. Initially (0 min), the solution exhibited a deep blue color, characteristic of unaltered MB. Over time, the color progressively lightened, reflecting the ongoing breakdown of dye molecules due to photocatalytic activity. The degradation percentages at the respective time intervals were 0%, 11%, 25%, 37%, 46%, 55%, 60%, 68%, 77%, and 89%, as illustrated in Fig. 7. This gradual increase confirms the sustained and steady photocatalytic decomposition of MB under sunlight irradiation, demonstrating the efficiency of Co_3O_4 nanoparticles as a visible-light-responsive photocatalyst.

Effect of pH concentration of Co_3O_4 NPs on Photocatalytic Degradation

The pH of the solution plays a significant role in influencing the surface properties of the catalyst and the availability of

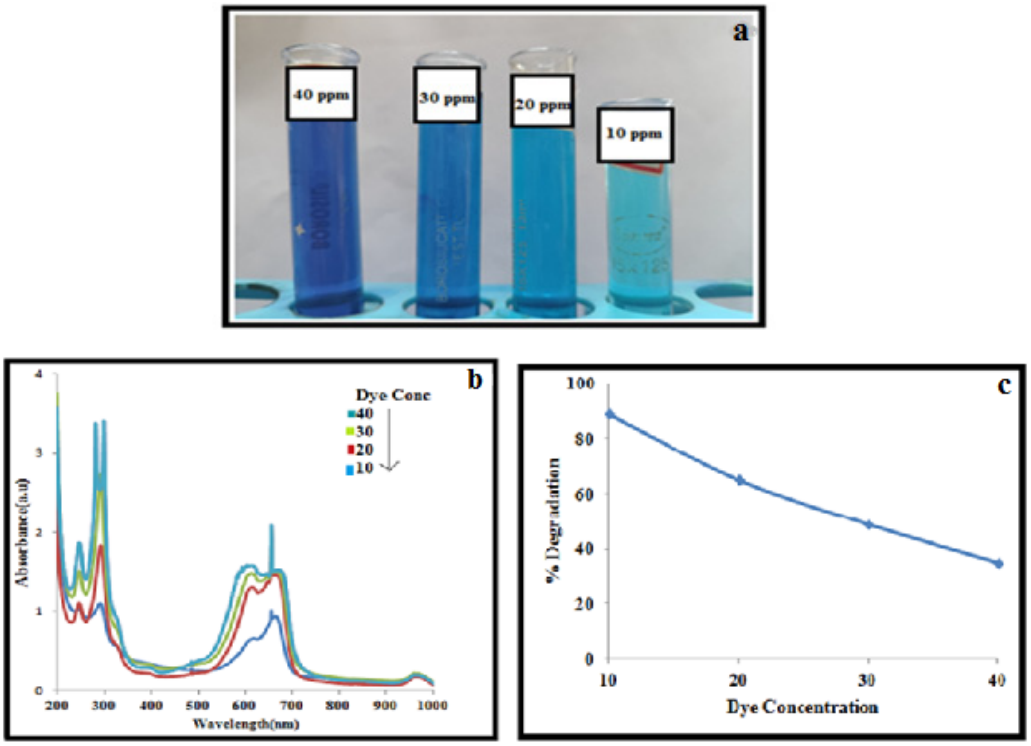

Fig. 6. (a) Visual discoloration of MB dye at different initial concentrations after 120 min.
(b) UV–Visible spectra of MB dye degradation at varying concentrations.
(c) Percentage degradation of MB dye after 120 min.

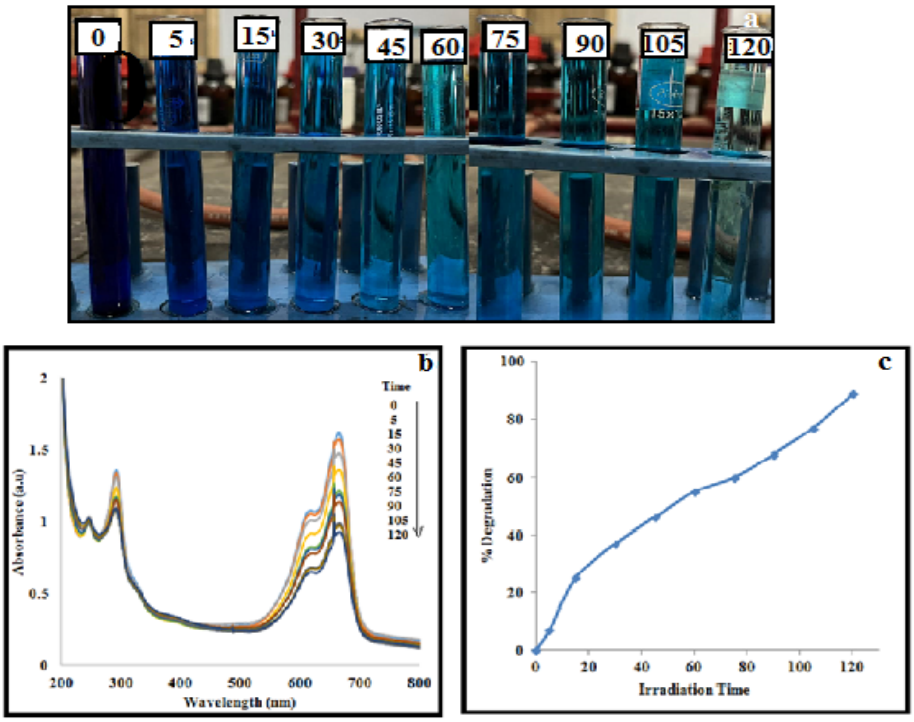

Fig. 7. (a) Time-dependent discoloration of MB dye during photocatalytic degradation, (b) UV–Visible spectra recorded at different reaction times, (c) Percentage degradation of MB dye as a function of time.

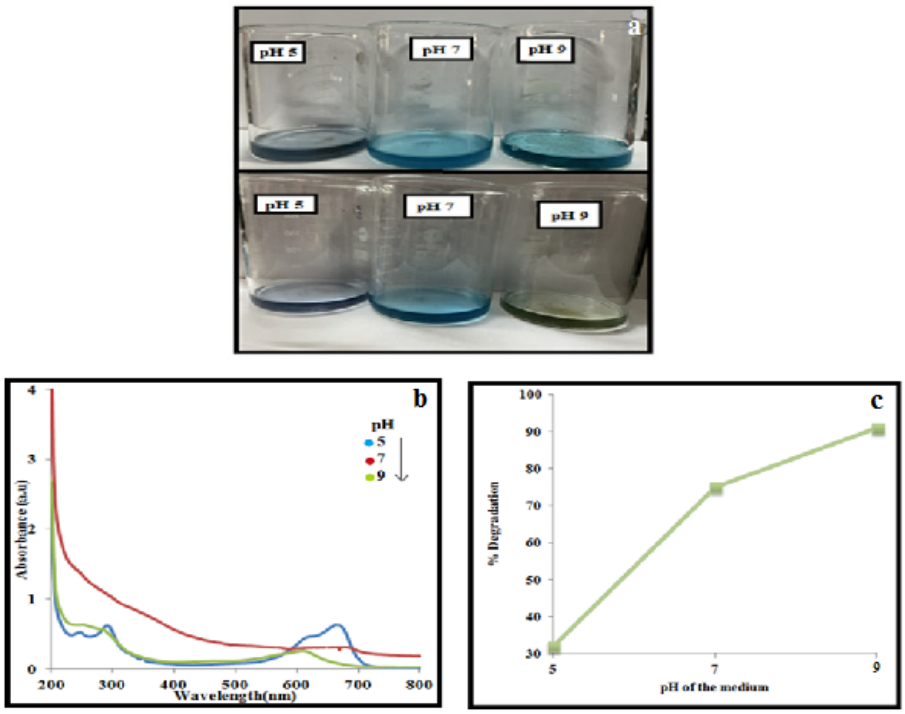

Fig. 8. (a) MB dye solutions before and after degradation at pH 5, 7, and 9, (b) UV–Visible spectra after 120 min at different pH values, (c) Percentage degradation of MB dye at varying pH levels.

J Water Environ Nanotechnol, 2026, 11(3): 395-404
10.22090/jwent.2025.2077526.2007

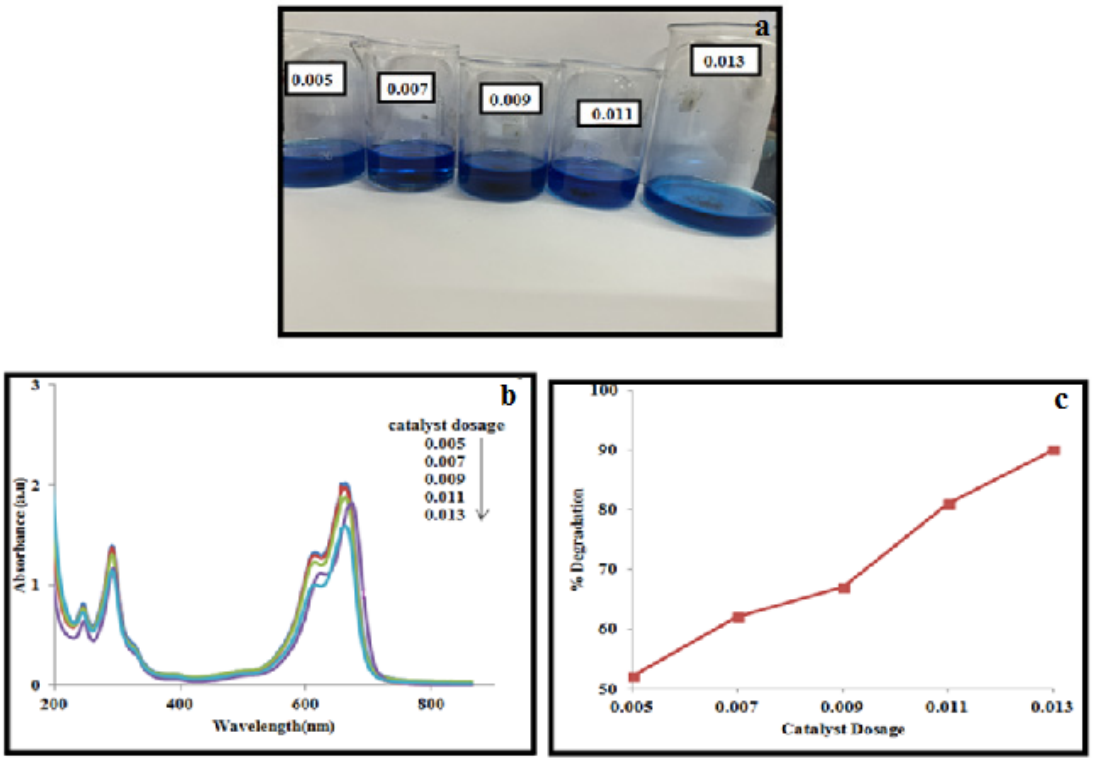

Fig. 9. (a) Effect of catalyst dosage on MB dye degradation, (b) UV–Visible spectra after 120 min using different catalyst amounts, (c) Percentage degradation of MB dye as a function of catalyst loading.

dissolved ions, thereby affecting dye degradation. Industrial effluents from paints, dyes, and textiles are often released at varying pH levels, making pH an important factor in photocatalytic processes. In this study, the photocatalytic degradation of methylene blue (MB) was investigated at pH values of 5, 7, and 9. The pH is particularly important for the generation of hydroxyl (•OH) radicals during degradation, which are key to breaking down dye molecules. Photographs of MB solutions before and after sunlight-driven photodegradation at different pH values are shown, illustrating the effect of pH on the degradation efficiency.

The figures show the initial MB solutions before degradation, characterized by their dark and intense coloration corresponding to the unaltered dye at different pH levels. The lower panel displays the solutions after photocatalytic treatment, which appear lighter and less intensely colored, indicating dye breakdown. Higher pH values promote the generation of active hydroxyl (•OH) radicals, enhancing the degradation of MB molecules [29]. As shown in Fig. 8, the degradation efficiencies at pH 5, 7, and 9 were 32%, 75%, and 91%, respectively, demonstrating that alkaline conditions favor photocatalytic dye degradation.

Effect of Catalyst Dosage on Photocatalytic Degradation

The effect of catalyst dosage on MB degradation was studied using Co_3O_4 nanoparticles at 0.005, 0.007, 0.009, 0.011, and 0.013 g per 20 mL of dye solution over 120 minutes.

Photographic images and UV–visible spectra show that increasing the catalyst amount enhances the degradation of MB dye. Higher catalyst dosages provide a larger surface area and more active sites, facilitating greater interaction with dye molecules and increasing the generation of photogenerated electrons. However, at excessively high dosages, aggregation or agglomeration of nanoparticles can reduce the number of accessible active sites. Overall, the degradation efficiency of MB improves with increasing Co_3O_4 nanoparticle dosage. Fig. 9 presents the percentage degradation of MB dye using different catalyst dosages over 120 minutes. The degradation efficiencies were 52%, 62%, 67%, 88%, and 90% for 0.005 g, 0.007 g, 0.009 g, 0.011 g, and 0.013 g of Co_3O_4 nanoparticles, respectively, indicating that higher catalyst amounts significantly enhance photocatalytic activity.

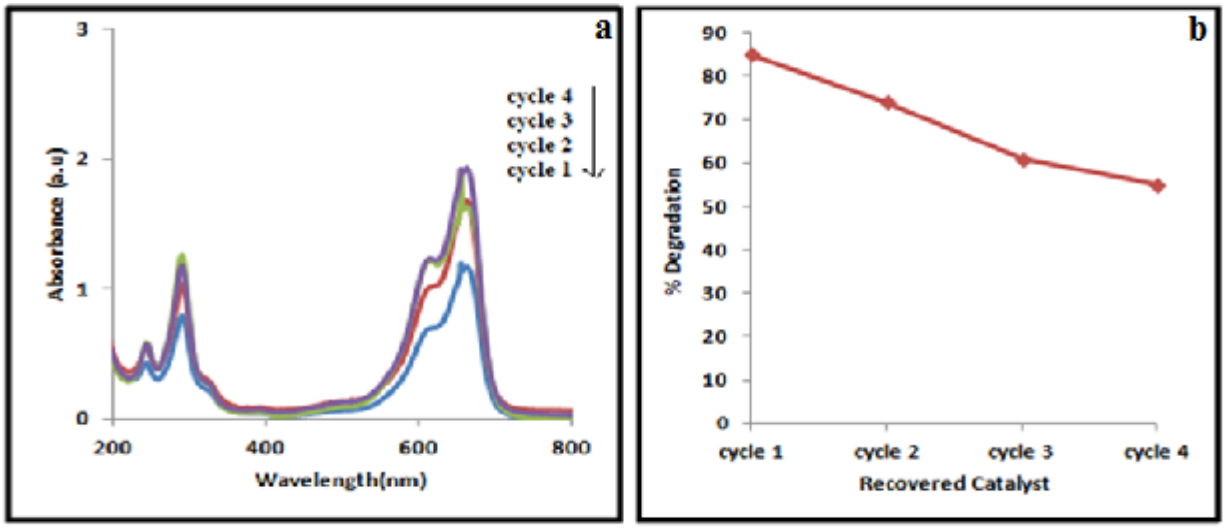

Fig. 10. UV–Visible spectra (a) and percentage degradation (b) of MB dye using the recovered Co_3O_4-NPs catalyst after 120 min, demonstrating catalyst reusability.

Effect of Recovered Catalyst Dosage on Photocatalytic Degradation

The reusability of Co_3O_4 nanoparticles was evaluated by performing photocatalytic degradation of methylene blue using the recovered catalyst. The previously optimized dosage of 0.013 g was reused after filtration and thorough washing with distilled water to remove impurities. The degradation study conducted over 120 minutes showed a gradual decline in photocatalytic activity, attributed to the partial blockage of active sites on the catalyst surface by deposited photosensitive hydroxides. The percentage degradation for cycles 1, 2, 3, and 4 was 85%, 74%, 61%, and 55%, respectively, as illustrated in Fig. 10, indicating that the catalyst retains significant activity but gradually loses efficiency upon repeated use.

CONCLUSION

Co_3O_4 nanoparticles synthesized from *D. palmatus* leaf extracts exhibited excellent photocatalytic activity for the degradation of methylene blue dye. After 120 minutes of sunlight irradiation, 89% of the dye was degraded, with longer exposure times further enhancing the degradation. Increasing the catalyst dosage improved degradation efficiency, with 90% of the dye degraded using 0.013 g of photocatalyst. Conversely, higher dye concentrations reduced photocatalytic efficiency. Additionally, alkaline conditions favoured dye removal, with 91% degradation achieved at pH 9, demonstrating that higher pH values enhance the photocatalytic breakdown of organic dyes.

Conflict of Interest
The authors declare no conflict of interest.

Funding
This study was not supported by any funding.

Author's Contributions
G.T. Parethe involved in manuscript drafting, data analysis and interpretation. G. Subashini involved in manuscript revision. All authors have approved the final manuscript and are responsible for all aspects of the work.

AI Statement
The authors confirm that no AI tools or services were used during the preparation of this work.

REFERENCES

1. Amdeha E. Recovery of nanomaterials from agricultural and industrial wastes for water treatment applications. In: Makhlouf ASH, Ali GAM, editors. Waste Recycling Technologies for Nanomaterials Manufacturing. Cham: Springer; 2021. p. 385-417. https://doi.org/10.1007/978-3-030-68031-2_14
2. Mostafa EM, Amdeha E. Enhanced photocatalytic degradation of malachite green dye by highly stable visible-light-responsive Fe-based tri-composite photocatalysts. Environ Sci Pollut Res Int. 2022;29(45):69861-69874. https://doi.org/10.1007/s11356-022-20745-6
3. Qiu R, Zhang D, Mo Y, Song L, Brewer E, Huang X, et al. Photocatalytic activity of polymer-modified ZnO under visible light irradiation. J Hazard Mater. 2008;156(1-3):80-85. https://doi.org/10.1016/j.jhazmat.2007.11.114

4. Shokri A. Degradation of 4-Chloro phenol in aqueous media thru UV/Persulfate method by Artificial Neural Network and full factorial design method. Int J Environ Anal Chem. 2020;102(2):534-550. https://doi.org/10.1080/03067319.2020.1791328
5. Royer B, Cardoso NF, Lima EC, Macedo TR, Airoldi C. A useful organofunctionalized layered silicate for textile dye removal. J Hazard Mater. 2010;181(1-3):366-374. https://doi.org/10.1016/j.jhazmat.2010.05.019
6. Sathasivam K, Pattulingam R, Manickavasagam B, Nagarajan V, Parethe GT. Photocatalytic degradation of methylene blue dye using MnO2 nanoparticles by Ziziphus Oenopolia (L.) Mill Leaf extract. J Water Environ Nanotechnol. 2025;10(3):310-319.
7. Mahmoodi NM, Salehi R, Arami M, Bahrami H. Dye removal from colored textile wastewater using chitosan in binary systems. Desalination. 2011;267(1):64-72. https://doi.org/10.1016/j.desal.2010.09.007
8. Singh J, Dhaliwal AS. Plasmon-induced Photocatalytic Degradation of Methylene Blue Dye Using Biosynthesized Silver Nanoparticles as Photocatalyst. Environ Technol. 2020;41(12):1520-1534. https://doi.org/10.1080/09593330.2018.1540663
9. Nagar N, Devra V. A Kinetic Study on the Degradation and Biodegradability of Silver Nanoparticles Catalyzed Methyl Orange and Textile Effluents. Heliyon. 2019;5(2):e01356. https://doi.org/10.1016/j.heliyon.2019.e01356
10. Kamat P. Manipulation of charge transfer across semiconductor interface a criterion that cannot be ignored in photocatalyst design. J Phys Chem Lett. 2012;3(5):663-672. https://doi.org/10.1021/jz201629p
11. Hammad A, Haitham M, El-Bery HM, EL-Shazly AH, Elkady M. Effect of WO3 Morphological Structure on its Photoelectrochemical Properties. Int J Electrochem Sci. 2018;13(1):362-372. https://doi.org/10.20964/2018.01.32
12. Velusamy P, Lakshmi G. Enhanced Photocatalytic Performance of (ZnO/CeO2)-β-CD System for the Effective Decolorization of Rhodamine B under UV Light Irradiation. Appl Water Sci. 2017;7(7):4025-4036. https://doi.org/10.1007/s13201-017-0554-0
13. Khodaie M, Ghasemi N, Moradi B, Rahimi M. Removal of methylene blue from wastewater by adsorption onto ZnCl activated corn husk carbon equilibrium studies. J Chem. 2013;2013:830208. https://doi.org/10.1155/2013/383985
14. Dardouri S, Sghaier J. Adsorptive removal of methylene blue from aqueous solution using different agricultural wastes as adsorbents. Korean J Chem Eng. 2017;34(4):1037-1043. https://doi.org/10.1007/s11814-017-0008-2
15. Saghi M, Shokri A, Arastehnodeh A, Khazaeinejad M, Nozari A. The photo degradation of methyl red in aqueous solutions by α-Fe2O3/SiO2 nano photocatalyst. J Nanoanal. 2018;5(3):163-170.
16. Ibhadon AO, Fitzpatrick P. Heterogeneous photocatalysis: Recent advances and applications. Catalysts. 2013;3(1):189-218. https://doi.org/10.3390/catal3010189
17. Kumar S, Karthikeyan S, Lee AF. g-C3N4-based nanomaterials for visible light-driven photocatalysis. Catalysts. 2019;9(5):1-30. https://doi.org/10.3390/catal8020074
18. Nagajyothi PC, Muthuraman P, Sreekanth TVM, Kim DH, Shim J. Green synthesis: In-vitro anticancer activity of copper oxide nanoparticles against human cervical carcinoma cells. Arab J Chem. 2017;10(2):215-225. https://doi.org/10.1016/j.arabjc.2016.01.011
19. Ahmed S, Ahmad M, Swami BL, Ikram S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. J Adv Res. 2016;7(1):17-28. https://doi.org/10.1016/j.jare.2015.02.007
20. Gautam VP, Aslam PR, Bharati KU, Singhai AK. Diplocyclos palmatus: a phytopharmacological review. Int J Res Pharm Chem. 2013;3(1):157-159.
21. Khodaie M, Ghasemi N, Moradi B, Rahimi M. Green synthesis of Co3O4 nanoparticles using Euphorbia heterophylla L. leaves extract: Characterization and photocatalytic activity. Mater Sci Eng. 2019;509(1):012070. https://doi.org/10.1088/1757-899X/509/1/012105
22. Alminderej FM. Study of new cellulosic dressing with enhanced antibacterial performance grafted with a biopolymer of chitosan and myrrh polysaccharide extract. Arab J Chem. 2020;13(1):3672-3681. https://doi.org/10.1016/j.arabjc.2019.12.005
23. Liu J, Jin R, Qiao Y, Wu Y, Wang X, Wang Y. Determination of Lead (II) using glassy carbon electrode modified with hexagonal Co3O4 microparticles. Int J Electrochem Sci. 2018;13(11):10415-10426. https://doi.org/10.20964/2018.11.45
24. Anuradha CT, Raji P. Facile-synthesis and characterization of cobalt oxide (Co3O4) nanoparticles by using Arishta leaves assisted biological molecules and its antibacterial and antifungal activities. J Mol Struct. 2022;1252:132138. https://doi.org/10.1016/j.molstruc.2022.133065
25. Elkady MF, Hassan HS. Photocatalytic degradation of malachite green dye from aqueous solution using environmentally compatible Ag/ZnO polymeric nanofibers. Polymers (Basel). 2021;13(13):2033. https://doi.org/10.3390/polym13132033
26. Abukhadra MR, Shaban M, Abd El Samad MA. Enhanced photocatalytic removal of Safranin-T dye under sunlight within minute time intervals using heulandite/polyaniline nickel oxide composite as a novel photocatalyst. Ecotoxicol Environ Saf. 2018;162:261-271. https://doi.org/10.1016/j.ecoenv.2018.06.081
27. Sundar KP, Kanmani S. Progression of Photocatalytic reactors and its comparison: A Review. Chem Eng Res Des. 2020;154:135-152. https://doi.org/10.1016/j.cherd.2019.11.035
28. Hassaan MA, El Nemr A, Madkour FF. Testing the advanced oxidation processes on the degradation of Direct Blue 86 dye in wastewater. Egypt J Aquat Res. 2016;42(1):1-6. https://doi.org/10.1016/j.ejar.2016.09.004