SRI VENKATESWARA INTERNSHIP PROGRAM
FOR RESEARCH IN ACADEMICS
(SRI-VIPRA)
Minor Research Project (Grant)

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Project Report of 2025: SVPG-2502

"Eco-Engineered Biopolymer-Integrated Nanocatalysts for Smart and Selective Remediation of Toxic Pollutants from Environmental Matrices"

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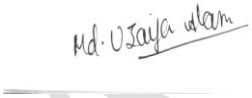
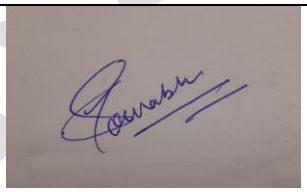
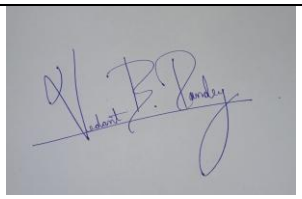
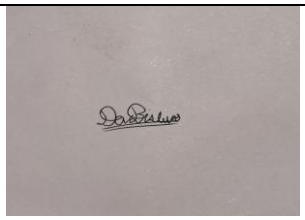
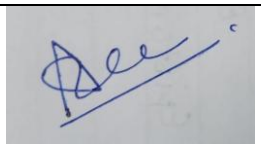
SRIVIPRA Minor Research Project (Grant) 2025

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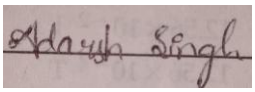
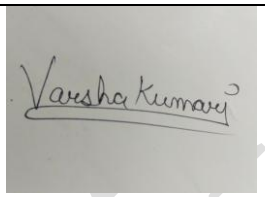
Name of Mentor: Dr. Shikha Gulati **Name of Department: Chemistry** **Designation: Assistant Professor**	
Name of Mentor: Dr. Laishram Saya Devi **Name of Department: Chemistry** **Designation: Assistant Professor**	

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List of students under the SRIVIPRA Minor Research Project

S.No	Photo	Name of the student	Roll number	Course	Signature
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4		Dev Biswas	1223069	B.Sc.(H) Biochemistry	
5		Anjali Rani	1123100	B. Sc.(P)Life Sciences	
6		Riddhi Grover	1124017	B.Sc. (P) Life Science	

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7		Adarsh Singh	1323066	BSc(H) biological sciences	
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Signature of Mentors

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Certificate of Originality

This is to certify that the aforementioned students from Sri Venkateswara College have participated in the summer project SVPG-2502 titled "**Eco-Engineered Biopolymer-Integrated Nanocatalysts for Smart and Selective Remediation of Toxic Pollutants from Environmental Matrices"**. The participants have carried out the research project work under my guidance and supervision from 1st July 2025 to 31st December 2025. The work carried out is original and was carried out in an offline mode.



Signature of Mentors

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1. Objectives

The primary objectives of this project are:

(i) To investigate recent advancements in nanocatalysts for environmental remediation.

(ii) To explore methods for the synthesis of nanocatalysts aimed at achieving enhanced catalytic efficiency, selectivity, and sustainability.

(iii) To analyze the characterization techniques employed for evaluating the structural, physicochemical, and catalytic properties of nanocatalysts.

(iv) To review the applications of nanocatalysts in the degradation, transformation, and removal of toxic pollutants, as well as in monitoring environmental remediation processes.

(v) To discuss future perspectives and potential breakthroughs in nanocatalyst technologies for smart, selective, and sustainable environmental remediation.

2. Abstract

The growing concern over environmental pollution has driven the development of nanocatalysts as innovative and efficient tools for environmental remediation. This report presents a comprehensive review of recent advancements in nanocatalysts and their applications in the degradation and removal of toxic pollutants from environmental matrices, including air, water, and soil. Various synthesis approaches, encompassing chemical, biological, and physical methods, have been employed to develop nanocatalysts with enhanced catalytic activity, selectivity, and environmental compatibility. The report highlights state-of-the-art characterization techniques used to evaluate the structural, physicochemical, and catalytic properties of nanocatalysts, as well as their role in accelerating pollutant transformation and detoxification processes. Finally, future research directions and emerging trends are discussed, aiming to promote the development of smart, sustainable, and eco-friendly nanocatalyst-based remediation technologies.

3. Introduction to Nanocatalysts

Nanocatalysts are catalytic materials engineered at the nanoscale that significantly enhance the rate and efficiency of chemical reactions involved in environmental remediation processes. Owing to their extremely high surface-to-volume ratio, tunable surface chemistry, and unique electronic and structural properties, nanocatalysts exhibit superior catalytic activity compared to their bulk counterparts. These characteristics enable effective interaction with pollutants, leading to accelerated degradation, transformation, or detoxification of harmful contaminants. Nanocatalysts have been increasingly explored for environmental remediation applications, including the removal of heavy metal ions, degradation of toxic organic pollutants, dyes, pharmaceuticals, and persistent emerging contaminants from air, water, and soil matrices. By facilitating advanced oxidation, reduction, and adsorption–

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catalysis mechanisms, nanocatalysts contribute to cleaner and more sustainable remediation technologies. Their ability to operate under mild conditions and their potential for recyclability make them attractive candidates for eco-friendly environmental management strategies.

4. Methods of Synthesis of Nanocatalysts

Several synthesis methods are employed in the development of nanocatalysts, each offering distinct advantages depending on the desired catalytic activity, selectivity, stability, and environmental application:

(i) Chemical Synthesis: Chemical approaches such as sol–gel methods, hydrothermal and solvothermal processes, co-precipitation, and chemical vapor deposition (CVD) are widely used for the synthesis of nanocatalysts. These techniques allow precise control over particle size, morphology, composition, and surface properties, which are critical parameters for optimizing catalytic efficiency and pollutant degradation performance.

(ii) Biological (Green) Synthesis: Biological or biogenic synthesis, employing plant extracts, microorganisms, enzymes, and biopolymers, has gained increasing attention due to its environmentally benign and sustainable nature. This approach produces nanocatalysts with enhanced stability, reduced toxicity, and improved environmental compatibility, making them particularly suitable for green remediation and eco-engineered applications.

(iii) (iii) Physical Synthesis: Physical methods such as laser ablation, sputtering, evaporation–condensation, and high-energy ball milling are utilized to produce nanocatalysts under controlled conditions, often in inert or vacuum environments. These techniques are preferred when high-purity, defect-controlled nanocatalysts are required for advanced catalytic applications.

Each synthesis method offers specific advantages in tailoring the structural and surface characteristics of nanocatalysts, enabling their effective use in smart and selective environmental remediation processes.

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Figure 1. Synthesis of Copper oxide nanoparticles via the Green method using phytochemicals

5. Characterization Techniques

To evaluate the structural, physicochemical, and catalytic properties of nanocatalysts and to ensure their effective performance in environmental remediation, a range of characterization techniques is employed:
(i) Transmission Electron Microscopy (TEM): TEM is used to examine the morphology, particle size, and nanostructure of nanocatalysts at high resolution. It provides detailed insights into size distribution, shape, and dispersion, which directly influence catalytic activity.
(ii) X-ray Diffraction (XRD): XRD is utilized to determine the crystalline structure, phase purity, and composition of nanocatalysts. Crystallinity and phase identification are crucial for understanding structure–activity relationships in catalytic processes.
(iii) Fourier-Transform Infrared Spectroscopy (FTIR): FTIR analysis is employed to identify surface functional groups, chemical bonding, and interactions between nanocatalysts and biopolymers or stabilizing agents. These surface characteristics play a vital role in pollutant adsorption and catalytic selectivity.
(iv) Dynamic Light Scattering (DLS): DLS is used to measure particle size distribution and colloidal stability of nanocatalysts in suspension. Stability and uniform dispersion are important factors affecting catalytic efficiency in aqueous environmental systems.
(v) Electrochemical Techniques Electrochemical methods such as cyclic voltammetry are applied to study the redox behavior, electron transfer properties, and catalytic activity of nanocatalysts, particularly in processes involving electrochemical or photocatalytic remediation.
These characterization techniques are essential for optimizing the design, performance, and applicability of nanocatalysts in smart and sustainable environmental remediation technologies.

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6. Applications of Nanocatalysts for the Removal of Toxic Pollutants from Environmental Matrices

Nanocatalysts have emerged as highly effective materials for the remediation of toxic pollutants from diverse environmental matrices due to their high catalytic activity, large surface area, and tunable surface properties. Their applications span water, air, soil, and wastewater treatment systems, contributing significantly to environmental health protection and sustainability.

(i) Water Remediation: Nanocatalysts are extensively used for the removal of toxic contaminants such as heavy metal ions (e.g., mercury, lead, cadmium, and arsenic), organic dyes, pharmaceuticals, and pesticides from water bodies. Through catalytic degradation, reduction, or adsorption-assisted processes, nanocatalysts enable efficient pollutant removal even at trace concentrations, thereby improving water quality and safety.

(ii) Wastewater Treatment: In wastewater treatment systems, nanocatalysts are integrated into advanced treatment processes such as photocatalysis, electrocatalysis, and advanced oxidation processes. These systems enhance the degradation of complex and recalcitrant pollutants, reduce treatment time, and improve overall treatment efficiency while minimizing secondary pollution.

Overall, the application of nanocatalysts offers a smart, selective, and sustainable approach for the remediation of toxic pollutants across multiple environmental matrices, supporting improved environmental management and public health outcomes.

7. Conclusion & Future Outlook

The development of nanocatalysts has significantly advanced the field of environmental remediation by enabling efficient, selective, and sustainable removal of toxic pollutants from diverse environmental matrices. The incorporation of advanced nanomaterials, including metal and metal oxide nanoparticles, carbon-based nanostructures, and biopolymer-integrated nanocatalysts, has markedly enhanced catalytic activity, stability, and pollutant removal efficiency. These nanocatalysts facilitate rapid degradation, transformation, or immobilization of hazardous contaminants, thereby contributing to improved environmental quality and protection of public health.

Despite these advancements, several challenges remain, including catalyst stability under complex environmental conditions, recovery and reusability, potential environmental risks, and scalability for real-world applications. Future research should focus on the development of eco-engineered and multifunctional nanocatalysts with enhanced selectivity toward specific pollutant classes, improved durability, and minimal secondary pollution. Emphasis on green synthesis approaches, biopolymer integration, and the design of recyclable and magnetically recoverable nanocatalysts will further promote sustainable remediation technologies. With continued progress in nanotechnology and environmental engineering, nanocatalyst-based systems are expected to play a pivotal role in smart, efficient, and environmentally benign remediation strategies for safeguarding environmental health.

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