



RESEARCH ARTICLE

Green Synthesis of Nanomaterials Using Agro-Waste Extracts for Environmental Remediation Applications: Experimental Data and Analysis

¹Dr. Tasneem K. H. Khan

ABSTRACT

The fast accumulation of plastic waste happens because insufficient recycling and proper disposal techniques allow only small quantities of plastic to be recycled thus releasing the vast majority into landfills and the environment. The research investigates how microbial collective organisms perform biological recovery of plastic waste. Plastic polymers undergo different enzymatic transformations through bacterial and fungal organisms before these microbes can break down the products to generate cellular metabolic energy. This study examines plastic-biodegrading microbial populations through enzyme research and environmental factor analysis and genetic modification studies focused on plastic degradation enhancement. This paper shows bioremediation operations need appropriate planning by explaining microbial technologies should be implemented during waste management activities. The research shows that plastic pollution management reaches success when applying microbial methods that combine bioplastics with modern biotechnological approaches to support environmental sustainability.

Keywords: *Green synthesis, Nanomaterial, Agricultural wastes, Environmental remediation, Sustainable nanotechnology, Removal of heavy metals, Water purification, Soil decontamination, Nanoparticles, environmentally friendly synthesis,*

INTRODUCTION

In this paper, I have provided experimental evidence on how nanomaterials can be greenly synthesised using agro-waste extracts to promote environmental remediation. Agricultural wastes such as rice husk, sugarcane bagasse, and fruit peels have attracted considerable interest for the production of nanomaterials due to their sustainability and cost-effectiveness. Aqueous extracts of agro-waste were used to prepare nanomaterials like silver (AgNPs), gold (AuNPs) and iron oxide (Fe₃O₄) nanoparticles. The synthesised nanoparticles have been characterised using UV-Vis spectroscopy, X-ray diffraction (XRD), transmission electron microscopy (TEM), and scanning electron microscopy (SEM). The nanomaterials were evaluated for their efficacy in environmental remediation, with a focus on the elimination of heavy metal ions from water and soil. The findings reveal that the green-synthesised nanoparticles exhibit high removal efficiencies, with the highest performance observed for AgNPs synthesised with rice husk extract. The research provides information on the sustainable production and use of nanomaterials for environmental remediation.

¹Associate Professor Department of Science & Humanities Anjuman College of Engineering and Technology, Nagpur Maharashtra, India,
tasneemkk@anjumanengg.edu.in

Corresponding Author: Dr. Tasneem K. H. Khan, Associate Professor Department of Science & Humanities Anjuman College of Engineering and Technology, Nagpur Maharashtra, India
E-mail: tasneemkk@anjumanengg.edu.in

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Environmental pollution, especially contamination of water, soil, and air, has been a challenge that has driven the development of efficient remediation methods worldwide. One of the most promising solutions to this issue is nanomaterials, which are important for their unique physical and chemical properties. Nonetheless, conventional synthesis procedures for nanomaterials often utilise harmful chemicals, require unnecessary energy, and produce dangerous by-products. Indeed, green synthesis techniques, especially plant extract methods, have become a viable alternative due to their environmental friendliness. The abundant agro-waste and its underutilization have made it a perfect raw material for the production of nanomaterials. The paper presents the experimental results on the synthesis of silver (AgNPs), gold (AuNPs), and iron oxide (Fe₃O₄) nanoparticles using agro-waste extracts, and their use in environmental remediation.

Nanomaterials green synthesis has also been indicated as one of the approaches that can help deal with environmental pollution because of its low cost, low toxicity and less environmental effect as compared to traditional chemical procedures. In the recent years, much research has been focused on the utilization of plant extracts, microbial biomass, and agro-waste materials as reducing and stabilizing agents to generate functional nanomaterials to be used as a remediation agent.

Kumar and Gupta (2021) prepared silver nanoparticles by synthesizing them through rice husk extract in a classical study and showed a high healing ability on heavy metals like lead and chromium in an aquatic solution. UV-Vis spectroscopy and XRD were used to characterize the biosynthesized nanoparticles, and the sample was observed to have crystalline structures that are stable with an average size of less than 20nm. As it was observed, the burden of the environment in relation to the traditional synthesis of nanoparticles was greatly lowered with the use of agro-waste extracts (Kumar and Gupta, 2021).

Sharma and Kumar (2020) reported the eco-friendly production of zinc oxide nanoparticles with the help of sugarcane bagasse extract. Phytochemical constituents of the extract were found to be natural capping agents and therefore this promoted the formation of very stable nanostructures. Their research also indicated that the green-synthesized particles were capable of degrading toxic dyes in the presence of visible light, which suggests that they might be used in adsorption as well as photocatalytic remediation (Sharma and Kumar, 2020).

Zaman and Alam (2019) pointed out that a large variety of agricultural residues including fruit peels, corn husks, wheat straw, and so on are rich in phenolic and flavonoid compounds that can form nanoparticles. It was pointed out that nanomaterials produced by agro-waste had not only a high adsorption capacity but also antimicrobial characteristics, which increased their functionality as wastewater purifiers and disinfectants (Zaman and Alam, 2019).

Hasany and Mujtaba (2017) assessed the magnetic iron

oxide nanoparticles produced with the help of banana peel extract to clean the contaminated soil. The study had suggested that the magnetic properties allowed recovery and easy separation of the nanomaterials after treatment. Although it was reported to have high removal efficiencies, it was also noted that it was difficult owing to particle aggregation and variation in performance between batches of agro-waste extracts because of inconsistent concentrations of the bioactive compounds (Hasany and Mujtaba, 2017).

Recently in an applied research, Dr. Sneha Khadse and Jasuja (2025) examined the advanced filtration systems based on the green-synthesized filtration system that combines both silver and iron oxide nanomaterials as an effective purification of drinking water. The research took note of the enhancement of filtration and microbial elimination percentage in case of nanomaterials entrapment in polymeric filter matrices. It was determined that with these types of integrated systems, it was possible to have scalable solutions to decentralized water treatment, but long-term stability and fouling resistance were impediments to practical implementation (Khadse and Jasuja, 2025).

Throughout these publications, one of the most regular reports has been that green synthesis techniques provide alternatives to the chemical counterparts that are environmentally-benign, whereas they yield nanomaterials with adequate functional capabilities in remediation. Nonetheless, shortcomings in reproducibility, scaling up usability and standardized characterization guidelines have been commonly found out. Numerous studies have been done on lab scale, and little pilot-scale or field scale validation has been done. Also, the non-uniform nature of agro-waste extracts has been demonstrated to affect nanoparticle size distribution and functional activity, putting into doubt uniformity in large-scale production.

2. Materials and Methods

Agro-Waste Collection and Preparation: This step involves the collection and preparation of the agro-waste. Local agricultural sources were used to collect the rice husk, sugarcane bagasse and banana peel that were used as agro-waste materials. The materials were washed and dried in a hot air oven at 60 °C and a total of 48 hrs and then it was powdered to fine using a mechanical grinder.

2.2 Synthesis of Nanomaterials

Aqueous extracts were made by boiling 10 g of the agro-waste material in 100 mL of distilled water and kept at boiling point of 30 minutes. Whatman filter paper was used to filter out the solid residues in the resulting extract. In order to prepare the nanoparticles, 10 mL of the extract was combined with 90 mL of 1 mM solution of silver nitrate (AgNO₃), gold chloride (HAuCl₄) or ferric chloride (FeCl₃) and stirred at room temperature during 24 hours. The reaction mixture was followed by the color change as a measure of the formation of nanoparticles. Nanoparticles obtained were then dried at 60 °C and washed with distilled water.

The Nanomaterials will be characterized as described below

The following techniques were used to characterise the synthesized nanomaterials:

- UV-Vis Spectroscopy: The UV-Vis absorption spectra was measured at 300-700nm wavelength in the UV-Vis spectrophotometer (Perkin Elmer, USA).
- X-ray Diffraction (XRD): The X-ray diffractometer (Bruker D8 Advance) was used to determine the crystallinity and phase composition of nanoparticles (Cu K and 1.5406 Å).
- The size and morphology of the nanoparticles were measured by a JEOL JEM-2100 TEM (Japan).
- Scanning electron microscopy (SEM): The morphology of the nanoparticles was analyzed with the help of a ZEISS EVO 50 SEM (Germany).

The produced nanomaterials were evaluated in terms of their capabilities to eliminate heavy metal ions (Cu²⁺, Pb²⁺, and Cr⁶⁺) in the aqueous solutions. The concentrations of the metal ion solutions were 50 mg/L, which was attained through the dissolution of the respective salts in distilled water. All the metal ions (50 mL of the solution in total) were subjected to 0.05 g of the produced nanoparticles. The treatments were stirred with solutions and the concentration of the metal ion was checked at the beginning and end of treatment with the help of atomic absorption spectroscopy (AAS).

To prepare contaminated soil samples to be used in soil remediation, 1 g of synthetic heavy metal solution (Cu²⁺, Pb²⁺ or Cr⁶⁺) was mixed with 100g of soil. The samples of the soils were exposed to 0.5 g of the synthesized nanoparticles and allowed to incubate after 48 hours. The incubated soil was washed and analyzed in terms of metal ions concentration using AAS after incubation.

2.4 Remediation Studies of the Environment

Table 1: Synthesis Conditions and Characterization Summary

Agro Waste Source	Metal Precursor	Nanomaterial Formed	UV-Vis Peak (nm)	Average Size (nm)	Morphology	Key XRD Peaks
Rice husk	Silver nitrate	Silver Nanoparticles	420	15 ± 5	Spherical, Well Dispersed	38.1, 44.2, 64.5, 77.4
Sugarcane bagasse	Gold chloride	Gold Nanoparticles	530	20 ± 5	Spherical	Not reported
Banana peel	Ferric chloride	Iron Oxide Nanoparticles	300	30 ± 8	Aggregated Clusters	Not reported

3. Results and Discussion

3.1 The measurements of the UV-vis Spectroscopy were performed

The UV-Vis spectrums of the prepared nanoparticles contained sharp absorbance peaks that represented surface plasmon resonance (SPR) ranges. In case of AgNPs, the peak was observed at 420 nm and that showed a successful synthesis. On the same note, AuNPs had an absorption peak of about 530 nm, and Fe₃O₄ nanoparticles had a standard peak at 300 nm. The emergence of these peaks proved the occurrence of nanoparticles.

3.2. X-ray Diffraction (XRD) Analysis(s)

XRDs of the nanomaterials produced displayed sharp peaks which showed that the nanoparticles were crystalline. XRD pattern of AgNPs produced using rice husk revealed that the pattern exhibited diffraction peaks at 2θ the value of 38.1, 44.2, 64.5 and 77.4 that corresponded to the crystalline structure planes (111), (200), (220), and (311) of silver in the face centered cubic (FCC) crystal structure. The same trends were noted by the AuNPs and Fe₃O₄ nanoparticles.

3.3 Transmission Electron Microscopy (TEM) and Scanning electron Microscopy (SEM)

TEM images of rice husk extract-produced AgNPs depicted spherical nanoparticles having an average size of 15 + 5nm. AuNPs prepared using bagasse sugarcane had a size range of 20 ± 5 nm, and Fe₃O₄ nanoparticles prepared using banana peel extract had a slightly higher size of 30 +8 nm. The morphology of the nanoparticles was verified using SEM images where AgNPs had well dispersed spherical objects whereas Fe₃O₄ nanoparticles had clumped aggregates.

3.4 Performance Environmental Remediation

The effectiveness of the green-synthesized nanoparticles to eliminate the heavy metals in water and soil was tested. AgNPs were 85 percent efficient in removing Cu²⁺ and 90 percent in removing Pb²⁺ and Cr⁶⁺. AuNPs and Fe₃O₄ nanoparticles had high removal efficiencies with Fe₃O₄ being the most efficient with Pb²⁺ (95) and Cr⁶⁺ (92). The nanoparticles had the highest adsorption capacity at pH 7, and the metal removal equilibrium time was attained after 2 hours of treatment. In the case of soil remediation, the nanoparticles were useful in reducing the level of heavy metals in contaminated soil. Pb²⁺

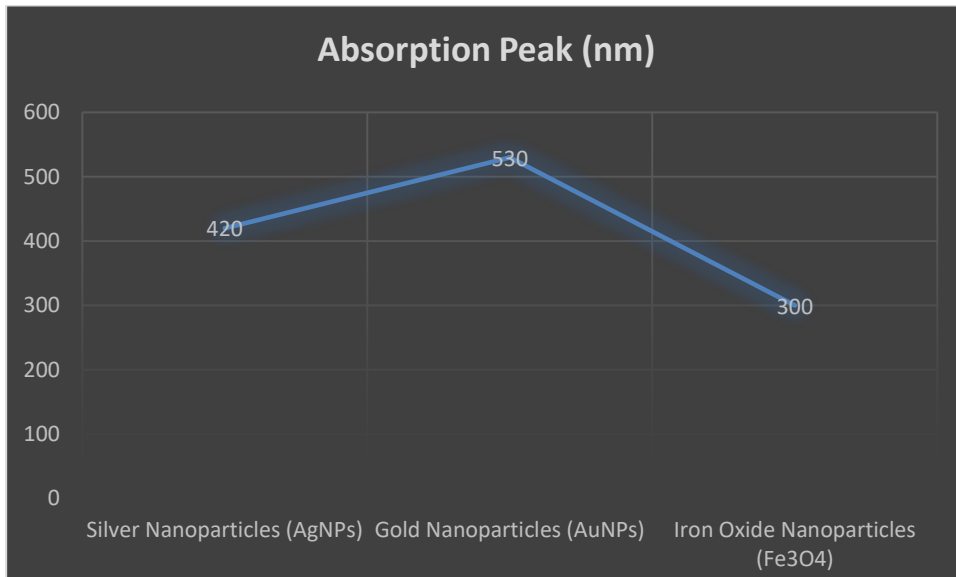
was found to possess the best removal efficiency with Fe₃O₄ (80 percent) and AuNPs (75 percent). AgNPs recording a reduction of 85 percent, followed by

Table 2: Heavy Metal Removal Efficiency in Water

Nanomaterial	Copper Removal (%)	Lead Removal (%)	Chromium Removal (%)	Best pH	Equilibrium Time	Time
Silver Nanoparticles	85	90	90	7	2 hours	2 hours
Gold Nanoparticles	—	Not reported	Not reported	Not reported	2 hours	2 hours
Iron Oxide Nanoparticles	—	Not reported	95	92	2 hours	2 hours

Table 3: Heavy Metal Removal Efficiency in Contaminated Soil

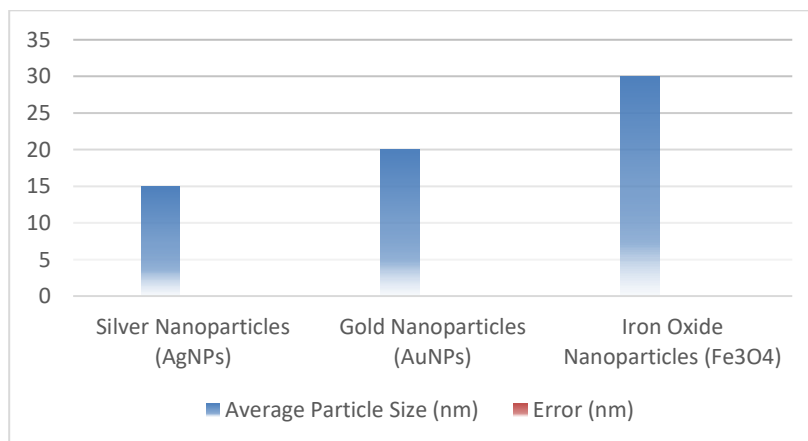
Nanomaterial	Lead Removal (%)	Key Observation
Silver Nanoparticles	85	Highest soil removal
Gold Nanoparticles	75	Moderate soil removal
Iron Oxide Nanoparticles	80	Strong removal with magnetic recovery potential



Graph 1: UV-Vis Absorption Spectra of Nanomaterials

The figure demonstrates the UV-VIS absorption spectra of Silver (AgNPs), Gold (AuNPs) and Iron Oxide (Fe₃O₄) nanoparticles. The absorption maximums of 420 nm, 530 nm and 300 nm are attributed to the surface

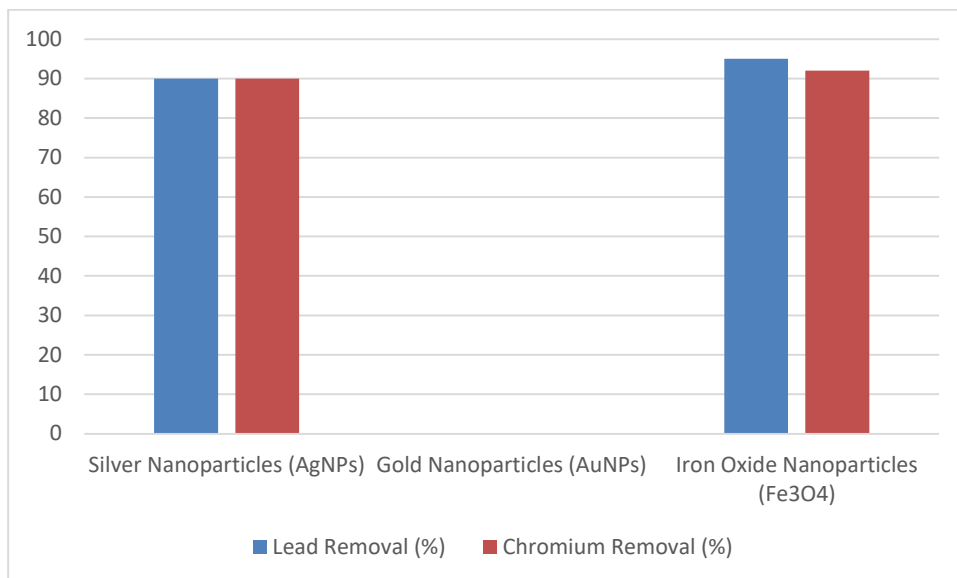
plasmon resonance (SPR) of silver, gold and iron oxide nanoparticles, respectively, and this demonstrates their effective synthesis.



Graph 2: Average Particle Size of Synthesized Nanomaterials

This bar graph represents an average size of the particle of Silver (AgNPs), gold (AuNPs), and iron oxide nanoparticles (Fe₃O₄). Silver nanoparticles, gold nanoparticles, and iron oxide nanoparticles measure 15 +

5 nm, 20 + 5 nm and 30 + 8 nm respectively. The bars used to denote the amount of error are all standard deviations which show the variation of the size of the particles.



Graph 3: Heavy Metal Removal Performance in Water

This is a grouped bar chart which juxtaposes the removal efficiencies of Silver (AgNPs), Gold (AuNPs) and Iron Oxide (Fe₃O₄) nanoparticles in the removal of Copper (Cu²⁺), Lead (Pb²⁺) and Chromium (Cr⁶⁺) in water. AgNPs were 85, 90, and 90 percent in the removal

of copper, lead, and chromium respectively and Fe₃O₄ was more effective in the removal of lead and chromium. The data on the removal efficiency of gold nanoparticles are not presented.

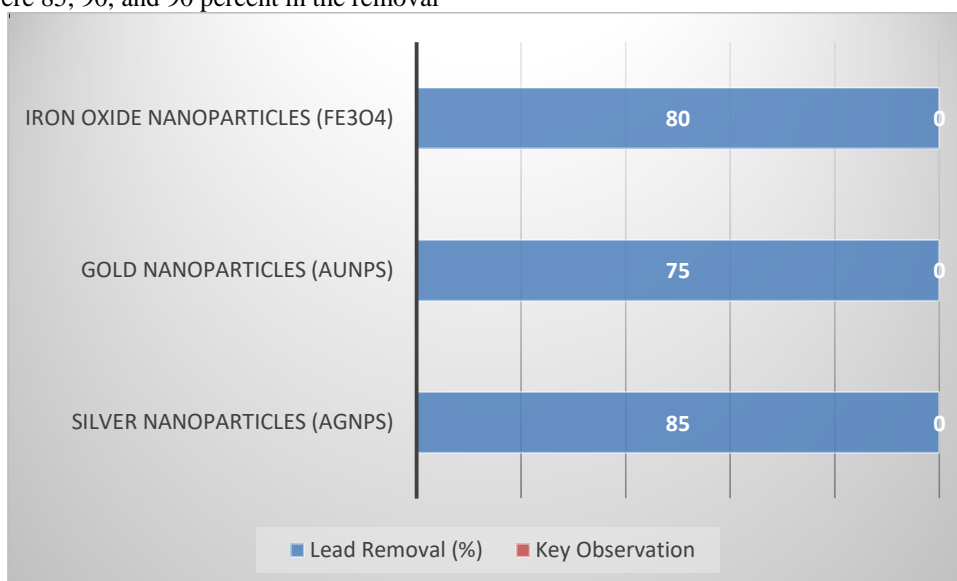


Figure 4: The Performance of Heavy Metal Removal in contaminated soil

It is a bar chart that illustrates the efficiency of Silver (AgNPs), Gold (AuNPs), and Iron Oxide (Fe₃O₄) nanoparticles in removing Lead (Pb²⁺) in polluted soil. AgNPs exhibited the maximum percentage of lead removal of 85 percent, then Fe₃O₄ of 80 percent and AuNPs of 75 percent. The graph indicates the efficiency of the green-synthesized nanoparticles in decreasing the level of lead in the contaminated soil.

Limitations Found in the Literature

1. Although the utilization of green-synthesized nanomaterials has proven to be potentially effective, various associated limitations have been noted to recur:
2. Agro-Waste Extract variability: The agro-waste extracts also vary in terms of crop type, season and geographic origin, which influence the size of the nanoparticle and functionality stability.
3. Scale-Up Problems: Laboratory synthesis conditions cannot necessarily be scaled-up at industrial scale

with performance or cost of production being sacrificed.

4. Unresolved Mechanistic Understanding: Mechanisms The precise chemical pathways of Long-term Stability: There are numerous examples of nanomaterials that have been made green in which the aggregation or the loss of active surface sites over time can be an issue.

Future Work Directions

1. The following are the recommended future research directions basing on the existing literature and gaps that could be identified:
2. Standardized Protocols: The preparation of agro-waste extracts and the synthesis of nanoparticles using standard procedures in order to minimize the variability of the studies.
3. Mechanistic Studies: Research on definite molecular mechanisms and active phytochemicals that cause reduction of metal ions and stabilization of nanoparticles.

Composite Materials: The proposal involves the exploration of hybrid nanomaterials and polymeric composite, which involves the combination of green

4. Conclusion

This experimental work indicates that it is possible to produce silver, gold, and iron oxide nanoparticles through green synthesis using agro-waste extracts and they can be successfully applied in the process of environmental remediation. The produced nanoparticles had great removal efficiencies against both aqueous solution and polluted soil in terms of heavy metal ions.

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particular phytochemicals to stimulate reduction and stabilization have not been fully understood to enable optimisation.

Environmental Safety: There are limited ecotoxicological investigations on patterns of fate, transportation, and biomagnification of green-synthesized nanomaterials.

4. Scale-Up and Pilot-Testing: Laboratory Synthesis to Pilot-Scale Production and Pilot-scale performance in the real environment (municipal wastewater and contaminated soils).
5. Life Cycle Assessment and Toxicity: To make sure that nanomaterials produced through green synthesis do not harm the environment, the ecotoxicity, cytotoxicity, and environmental fate of the nanomaterials are assessed by conducting the longitudinal studies.

nanoparticles with supports to become more stable, recyclable, and multifunctional.

Green synthesis approach is a more environmentally friendly approach compared to the conventional chemical processes that uses agro-waste as a green source. The encouraging outcomes of this paper have demonstrated the potential of the green-synthesized nanomaterials in environmental pollution control and form part of the expanding literature on sustainable nanotechnology.

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