

Green Synthesis of Silver Nanoparticles from Aqueous Seed Extract of *C. papaya* and its Application in Surface Water Resources Decontamination

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ABSTRACT

There have been reports of biological approaches, including the use of plant extract, for treating water in recent times. Water purification using green nanotechnology is an alternative to chemical and physical water treatments and is environmentally friendly, benign, green, cost-effective, safe, and easily sourced and scale up potable water for large scale synthesis. The purpose of this work is to synthesize silver nanoparticles from an aqueous seed extract of *C. papaya* and evaluate its application in water and wastewater decontamination. After obtaining the plant extract from *C. papaya*, it underwent phytochemical analysis. Silver nitrate solution was then utilized to create nanoparticles. The synthesized nanoparticle was examined using SEM, FT-IR, UV-Vis spectroscopy and XRD methods. The physicochemical and microbiological characteristics of the water samples subjected to 0.5 mg/mL of the produced nanoparticle at various intervals (30, 60, and 120 min) were examined both before and after treatment. The findings of the phytochemical studies indicated that alkaloids and tannins were present, while steroids and glycosides were not. The hydroxyl group was detected in the extract according to the FT-IR measurement. The UV-Vis test showed that at 400 nm, the absorbance was 2.598. The nanoparticle size range is consistent with the particle sizes found in the XRD data, which was 14.4 nm. Also, irregular, clustered, and sometimes crystalline or snowflake-like shapes were identified by the SEM results. Following nanoparticle treatment for 120 min, there were significant decreases ($P < 0.05$) in some physicochemical parameters of the different water resources treated. Therefore, it has been demonstrated that using biosynthesized silver nanoparticles from *C. papaya* aqueous seed extract in a variety of water and wastewater samples is beneficial for environmental processes such as disinfection.

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INTRODUCTION

Water free of pollution is a natural resource that is extensively needed in all human endeavours. Without it, the most essential aspects of man's life; health, food, energy, and economy are not safe (Kyriaki and Phoebe, 2009). Also, low quality water tends to pose great danger on the economic, environmental and public health especially among children and the impoverished (WHO and UNICEF, 2014). Waterborne problems have been reported to be responsible for the annual and daily losses of human lives which has been estimated to be about twenty million losses (Burakov *et al.*, 2017; Obiefoka *et al.*, 2023). Presently, it has been documented that billions of people living around the globe do not have access to potable water sources which results in major health cases. In addition to the challenges of water pollution confronted by mankind, there is limited access to existing potable water resources due to rising human populations and climatic changes in the coming future (Sumaila *et al.*, 2021).

Globally, water and wastewater are widely treated using various physical, chemical and biological procedures, but with their attendant disadvantages which include environmental toxicity, very high cost of operation and lesser efficiencies of treatment (Zekic *et al.*, 2018). Hence, there has been an intensified search and studies for other better and promising water treatment techniques.

At present, researchers have continued to exploit the applicability of silver metal nanoparticles in environmental discipline due to their spectacular and unique characteristics. The chemical and physical synthesis of silver nanoparticles have been widely documented but their attendant consequences such as release of environmental pollutants, long period of reaction, highly expensive, and complex procedures. The biological synthesis of metal nanoparticles is a better alternative to physical and chemical methods owing to the facts that they are environmentally - friendly, less expensive and less time required (Shittu and Ihebunna, 2017). Various substances are classified under the biological nanoparticle synthesis and these include plant extracts, microbes, enzymes and their metabolic by - products (Dhand *et al.*, 2016; Uba *et al.*, 2017; Dokubo *et al.*, 2022a; Anidu *et al.*, 2023). But plant extracts have been the most important among them due to their natural abundance and rich phytochemical ingredients which include terpenoids, polyphenols, sugars, flavonoids, alkaloids, phenolic acids, and proteins (Kamal *et al.*, 2020; Uba *et al.*, 2024). In recent times, nanoparticles (NPs) have demonstrated excellent biocidal activities against myriad microorganisms or a wide range of microorganisms at different laboratory incubation conditions as well as different water and wastewater with different chemical characters (Eltarahony *et al.*, 2016). This technology if applied in our country Nigeria could solve some of the country's crises thereby creating good drinkable water to some communities in rural areas.

Carica papaya seeds of a tropical tree comprise water-soluble and positively charged protein known as cystine protease which emerged as a putative coagulant in both water and wastewater treatments (Unnisa and Bi, 2018). Shittu and Ihebunna (2017) reported that the *Piliostigma thonningii* synthesized silver nanoparticle also showed heavy metal removal activity in laboratory simulated wastewater. Kamal *et al.* (2020) found that adding nanoparticles (100 μ L Cu, 50 μ L Ag, 150 μ L Ni / 50 mL water) removed nitrate and phosphate from water, while lower doses (30 μ L Cu, 30 μ L Ag, 75 μ L Ni / 50 mL) prevented bacterial growth. Most inhabitants of these studied areas located in Anambra and Imo States, Nigeria do not have access to potable water and therefore resort to depend on these water sources for domestic, agricultural and industrial activities. Although, literatures exist on the water qualities of these studied areas, there is paucity of any promising treatment regimens. Also, where information exists on any treatment and disinfecting techniques, there is none on the potential of *C. papaya* silver nanoparticle in decontamination water and wastewater to the best of our knowledge. The present study was undertaken to synthesize silver nanoparticles from an aqueous seed extract of *C. papaya* and evaluate its application in water and wastewater decontamination.

MATERIALS AND METHODS

Sample Collection

By adopting the methods of Dibua *et al.* (2020), Ibo *et al.* (2020) and Umeh *et al.* (2020), water samples used in this study were aseptically collected into 10 L sterile plastic containers at 3 different points and 5 cm depth using direct sampling and Bellas's methods from five studied areas which include: Neni Water Shed, Orsu Ihite-Ukwa (well water), Ukwaka River, Sacred Heart Waste Water Reservoir and Ulasi River, respectively. All the sites are located in Anambra and Imo States. A representative water sample was obtained for each site by mixing samples from the individual sampling points and immediately transported to Microbiology Postgraduate Laboratory, Chukwuemeka Odumegwu Ojukwu University Uli Campus Anambra State, Nigeria laboratory for further analysis.

Specimen Collection

C. papaya was obtained from a farm in Abubor Nnewichi Nnewi, Nnewi town in Nnewi North Local Government Area of Anambra State, Nigeria.

Extraction of the Plant Constituent

By adopting the methods of Shittu and Ihebunna, (2017) and Uba and Obiefuna, (2023), the moist fresh seeds of *C. papaya* were room dried for 2 weeks after cutting of the fruits and washing of the seeds with sterile clean water. The seeds were grounded to fine powdered form using an industrial electric blender at high-speed rate. Thereafter, 500 mL distilled water was used to dissolve 25 g weight of the *C. papaya* seed powder and heated at 80 °C for 25 min under magnetic stirring in a 1000 mL conical flask. The hot solution of the *C. papaya* seed powder was cooled and double filtered to obtain an aqueous extract which was later preserved in a refrigerator at 4 °C till further analysis.

Phytochemical Screening of the Aqueous Extract

Phytochemicals like phenols, tannins, alkaloids, terpenoids, steroids, saponins, flavonoids, glycosides, and proteins of *C. papaya* aqueous extract were tested using modified methods from various studies (Iheukwumere *et al.*, 2012a; 2012b; Mundi *et al.*, 2013; 2014; Okoye *et al.*, 2014; Uba *et al.*, 2016; Umeh *et al.*, 2021; Anameze *et al.*, 2023; Ezeamama *et al.*, 2025a; 2025b). Results will be shown as positive (+) or negative (-).

Synthesis of the Silver Nanoparticle

The green silver nanoparticles were synthesized via dropwise titration through drop wise addition of the aqueous extract into 5 mM aqueous silver nitrate (AgNO_3) solution under heating at 70 °C with magnetic stirrer till the observation of dark brown colour confirming silver nanoparticles synthesis (Shittu & Ihebunna, 2017; Okonkwo and Uba, 2025).

Characterization of the Synthesized Silver Nanoparticle

The physical and chemical characteristics of the synthesized green silver nanoparticle were determined using Ultraviolet-visible spectrophotometer (Ele *et al.*, 2025; Uba *et al.*, 2024), the Fourier-transform infrared spectroscopy (Okafor *et al.*, 2023; Dokubo and Uba, 2023), X - ray Diffractometer (Uba *et al.*, 2024) and scanning electron microscope (SEM) (Uba and Obiefuna, 2023; Ubani *et al.*, 2024).

Physicochemical Analysis of Water Sample

All physical and chemical analyses which include pH, temperature, PO₄, NH₃, SO₄, turbidity, COD and BOD₅ were performed according to Standard Methods of APHA (2012) as described by Kamal *et al.* (2020); Uba (2019); Uba *et al.* (2021) Egurefa *et al.* (2020a), (2020b); Dokubo *et al.* (2022b); Nwigwe *et al.* (2022), Nwigwe *et al.* (2023), Ibe *et al.* (2023), Alfred *et al.* (2023), Alfred *et al.* (2025), Chukwura *et al.* (2025), Okpalaunegbu *et al.* (2025), Uba *et al.*, 2025; Ubani *et al.* (2025), Dibua *et al.* (2020a); (2025b); (2025c); Okolo *et al.* (2025) and Enemchukwu *et al.*, 2026a; 2026b before and after treatment of the water samples.

Decontamination Potential Testing

In this study, the five (5) water samples were exposed with 0.5 mg/mL of the green silver nanoparticles and incubated at 30 °C for 120 min. The treated samples were taken at intervals of 30, 60 and 120 min and their physicochemical contents were determined as previously described above (Kamal *et al.*, 2020).

Biostatistical Management

The data obtained were statistically described in mean and standard deviation. The mean data were simultaneously subjected to two-factor analysis of variance (ANOVA) and Tukey multiple comparison test using GraphPad Prism Version 8.0.2. Statistical significance was set at the probability level less than 0.05 (Uba and Chukwura, 2016; Uba *et al.* 2018a; 2018b; 2018c; Uba, 2019a; 2019b; 2019c; Uba *et al.* 2019b; 2019c; 2019d; 2019e; Alisa *et al.*, 2020; Anukam *et al.*, 2020a; 2020b; Uba *et al.*, 2020a; 2020b; 2020c; 2020d; 2020e; 2020f; 2020g; Uba *et al.*, 2021a; 2021b; Ifediegwu *et al.* 2023a; 2023b; 2024a, 2024b; 2024c; Nnaka *et al.* 2024).

RESULTS AND DISCUSSION

In Nigeria, the most common source of drinking water for the rural population is from ponds, wells, rivers, stream, and borehole water. These water sources are usually consumed without treatment whatsoever. Nanobiotechnology treatment regimens have been widely accepted as it has several benefits over the conventional physical and chemical treatment regimens. This technology if applied in our country Nigeria could solve some of the countries crisis thereby creating good drinkable water to some communities in rural areas. In this study, the phytochemical screening of this plant to actually ascertain the presence of key capping and stabilizing phytochemicals showed that *C. papaya* is positive to all test except protein because protein are not found in *C. papaya* leaves

Table 1: Phytochemical outcome of the aqueous seed extract of *C. papaya*

Constituents	<i>C. papaya</i>
Phenols	+ve
Tannins	+ve
Alkaloids	+ve
Terpenoids	+ve
Steroid	+ve
Saponin	+ve
Flavonoid	+ve
Glycosides	+ve
Protein	-ve

Keys: +ve = positive result for a test; - ve = Negative result for the test

Also, it was observed that initially silver nitrate (AgNO₃) which was colourless began to change colour on heating on a magnetic stirrer at 70 °C, on drop wise addition of the plant extract within 24 hr. The results of the synthesis revealed that dark brown colour appeared after 24 hr upon constant heating, forming observable particles that are clearly seen. In order to confirm and identify the biogenic particles form, analysis conducted on the silver nanoparticles showed that in functional group composition (Figure 1A), the major and minor peaks ranges from 700 cm⁻¹ – 3800 cm⁻¹. These peaks detected the presence of strong C-O (carbohydrate group), N⁺ H (hydrogen bonded salts) and a medium O-H stretch vibrations assigned to O-H hydroxyl groups. In previous studies as reported by Shittu and Ihebunna, (2017); Okafor *et al.* (2023); Ubani *et al.* (2025) and Ele *et al.* (2025), hydroxyl groups are present due to polyphenol compounds embedded in the tannins which acts as reducing agents in the synthesis of silver nanoparticles. The XRD was used to determine the crystalline structures as seen in Figure 1B. The major peak for *C. papaya* (2θ = 38) with hkl values (110) corresponds to plane of face centered cubic silvers. These peak correlated with the standard Ag₂O (JCPDS 76-1393) as well as particle size as shown in Table 2 with the particle size of 14.4 nm. Azmath *et al.* (2016) showed silver nanoparticles had a crystalline structure, with XRD peaks at 38.2°, 44.42°, 64.5°, and 77.4°,

matching cubic facets. This matched with our study's findings. The result of the microscopic characteristics revealed that the bright white areas have a significantly higher average atomic number compared to the surrounding gray matrix. The darker black areas may represent voids, pores, or regions composed of very light elements. The bright particles exhibit irregular, clustered, and sometimes crystalline or snowflake-like shapes. There appear to be scratch marks or linear artifacts across the surface, especially diagonally through the center, possibly from sample preparation (polishing or cutting) or handling as shown in Figure 1C. Our SEM results match previous studies by Kamal *et al.* (2020), Okafor *et al.* (2023); Ubani *et al.* (2025), Ubani *et al.* (2024) and Ele *et al.* (2025) where plant extracts were used to synthesize nanoparticles. The result of UV-visible spectra as shown in Figure 1D indicated a strong surface plasmon resonance which is clearly visible at a peak of 400 nm. This is in accordance with previous works by Shittu and Ihebunna (2017), Dokubo and Uba (2023) and Uba *et al.* (2024) on silver nanoparticle green synthesis that range of wavelength is within 400 – 500nm.

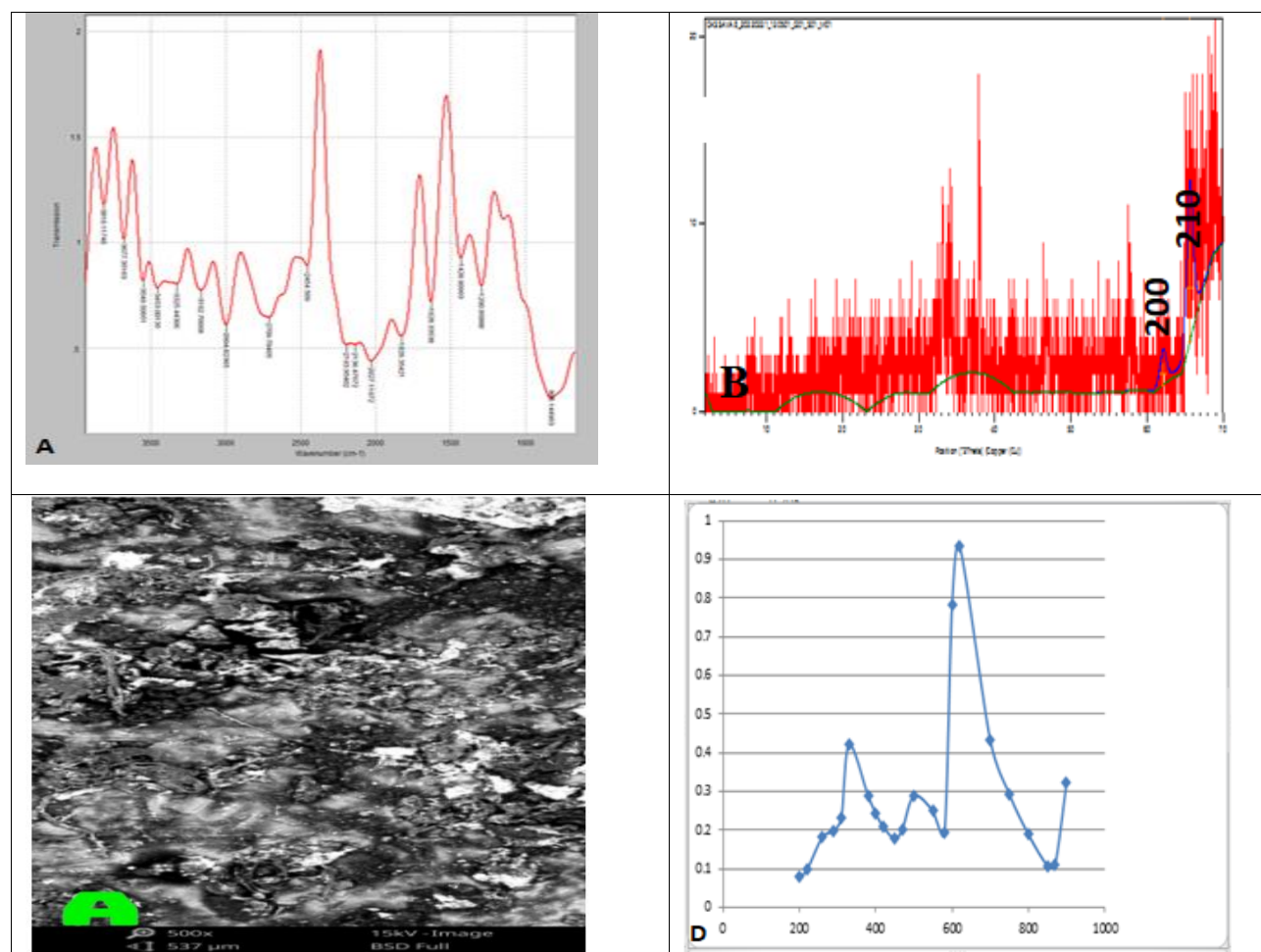


Figure (1A): FT-IR of *C. papaya* synthesized AgNPs;(1B): XRD pattern of AgNPs biosynthesized by *C. papaya* (1C): Scanning electron microscopy image (500X) of the AgNPs synthesized using *C. papaya* and (1D): UV-VIS spectral of *C. papaya*

Table 2: The XRD profile of the *C. papaya* green synthesized silver nanoparticles

Synthesized AgNPs	2 θ	Cos θ	Sin θ	FWHM	β radian	Crystalline size 'D' nm	Hkl identified from peak
<i>C. papaya</i>	38.44	0.94421	0.3293	0.5760	0.0101	14.6	110

Keys: AgNPs = Silver nanoparticles; θ = Theta; FWHM= full width at half maximum; β = Beta; hkl= integers representing lattice planes.

The result for the treatment of water samples with the synthesized silver nanoparticles using the same concentration (0.1 mg/ml) on the same quantity (500 mL) at different contact time (30, 60 and 120 min) is shown in Tables 3A - E. From Table 4.3A, *C. papaya* synthesized silver nanoparticles treated water sample gave the highest pH value (8.64) at 60 min; highest temperature was 28.6 °C; highest value of NH₃ (201.85 mg/ mL) at 30 min; the highest value of SO₄ (23.59 mg/ mL) at 120 min; the highest COD value (1440 mg/ L) at 30 min and highest BOD₅ (10.875 ppm) at 60 min, respectively. From Table 4.3B, *C. papaya* synthesized silver nanoparticles treated water sample gave the highest pH value (8.76) at 30 min; highest temperature was 28.6 °C; highest value of NH₃ (40.35 mg/ mL) at 30 min; the highest value of SO₄ (26.69 mg/ mL) at 30 min; the highest COD value (768 mg/ L) at 30 min and then highest BOD₅ (6.125 ppm) at 60 min, respectively. From Table 4.3C, *C. papaya* synthesized silver nanoparticles treated water sample gave the highest pH value (8.72) at 120 min; highest temperature was 28.3 °C; the highest value of SO₄ (80.02 mg/ mL) at 30 min and then with highest BOD₅ (5.750 ppm) at 30 min, respectively.

From Table 4.3D, *C. papaya* synthesized silver nanoparticles treated water sample gave the highest pH value (8.74) at all the min; highest temperature was 28.7 °C; highest value of NH₃ (25.35 mg/ mL) at 30 min, the highest value of SO₄ (28.12 mg/ mL) at 30 min, highest turbidity (9.46 NTU) at 60 min and then the highest COD value (720 mg/ L) at 30 min, respectively. From Table 4.3E, *C. papaya* synthesized silver nanoparticles treated water sample gave the highest pH value (8.77) at 30 min, highest temperature was 28.3 °C; the highest value of SO₄ (17.64 mg/ mL) at 60 min, the highest COD value (720 mg/ L) at 30 min and then highest BOD₅ value (7.125 ppm) at 30 min, respectively. The reduced effectiveness of biosynthesized particles and calcium hypochlorite on the tested physicochemical parameters might be due to nanoparticle aggregation, reducing surface area and reactivity. Notably, *C. papaya*-derived silver nanoparticles worked almost as well as commercial calcium hypochlorite. Statistically, there were non-significant ($P > 0.05$) differences detected among the means of treatment time while there were significant ($P < 0.05$) differences detected among the means of physicochemical parameters, respectively. This implied that once there was contact between the silver nanoparticle and the water samples, time does not necessarily affect the reduction process but the physicochemical parameters do. Our experimental findings aligned with the published studies of Kamal *et al.* (2020), Dokubo and Uba (2023) and Uba and Okonkwo (2025) who found that silver nanoagents were effective at removing some physicochemical parameters from different water resources.

Table 3A: Physicochemical effect of Ag-NPS on sample A Neni Water Shed

Agent	Parameters	Untreated	Treated (Min)		
		control	30	60	120
<i>C. papaya</i>	pH	5.75±1.25	8.63±0.09	8.64±0.01	8.62±0.01
	Temp. (°C)	26.40±1.78	28.60±0.03	28.60±0.03	28.60±0.03
	PO ₄ (mg/mL)	34.30±3.62	23.04±0.02	23.48±0.02	33.48±0.02
	NH ₃ (mg/mL)	0.38±0.05	201.85±0.70	37.35±0.30	177.35±0.58
	SO ₄ (mg/mL)	294.07±4.78	21.45±0.33	19.67±0.12	23.59±0.19
	Turbidity(NTU)	529.08±1.24	161.38±0.26	281.38±0.03	274.85±0.02
	COD(mg O ₂ / L)	1,808.00±6.78	1440.00±2.00	1408.00±2.08	1367.00±2.00
	BOD ₅ (ppm)	29.13±3.78	15.00±0.01	10.88±0.01	8.13±0.01
CaOCl ₂	pH	5.75±1.25	8.85±0.03	8.90±0.01	8.87±0.01
	Temp. (°C)	26.40±1.78	26.80±0.01	26.80±0.20	26.90±0.11
	PO ₄ (mg/mL)	34.30±3.62	41.74±2.30	23.04±0.20	81.30±0.20
	NH ₃ (mg/mL)	0.38±0.05	99.35±0.09	101.85±1.26	118.85±0.01
	SO ₄ (mg/mL)	294.07±4.78	15.26±0.02	11.69±0.40	11.93±0.03
	Turbidity(NTU)	529.08±1.24	227.92±0.02	235.23±0.04	232.54±0.02
	COD(mg O ₂ / L)	1,808.00±6.78	1280.00±2.30	1168.00±2.10	1104.00±2.00
	BOD ₅ (ppm)	29.125±3.78	5.720±0.01	5.37±0.01	5.38±0.01

Key: Temp = Temperature, PO₄ = Phosphate, SO₄ = Sulfate, NH₃ = Ammonia, CaOCl₂ = Calcium hypochloride, mg/ L = Milligram per liter, ppm = part per million, AgNPs = Silver nanoparticles, COD = chemical oxygen demand, BOD₅ = Biological oxygen demand at Day 5.

Table 3B: Physicochemical effect of Ag-NPS on sample B Orsu Ihite-Ukwa well water

Agent	Parameters	Untreated	Treated (Min)		
		control	30	60	120
<i>C. papaya</i>	pH	6.75±1.45	8.76±0.01	8.70±0.04	8.70±0.01
	Temp. (°C)	26.40±1.76	28.60±0.015	28.60±0.10	28.60±1.11
	PO ₄ (mg/mL)	7.28±3.86	180.87±0.1	78.69±1.10	43.04±1.72
	NH ₃ (mg/mL)	34.30±7.47	28.85±0.02	39.85±0.02	32.85±0.01
	SO ₄ (mg/mL)	294.07±4.76	26.69±0.01	17.17±0.02	37.17±0.03
	Turbidity(NTU)	87.86±3.00	7.15±0.01	22.15±0.01	24.46±0.01
	COD(mg O ₂ / L)	1760.00±1.26	768.00±1.20	736.00±1.23	720.00±1.20
	BOD ₅ (ppm)	18.13±7.82	6.00±0.01	6.13±0.01	5.63±0.01
CaOCl ₂	pH	6.75±1.45	8.84±0.01	8.82±0.02	8.84±0.03
	Temp. (°C)	26.40±1.76	26.70±0.03	26.60±0.04	26.50±0.04
	PO ₄ (mg/mL)	7.28±3.86	180.87±0.01	78.69±0.01	43.04±0.01
	NH ₃ (mg/mL)	34.30±7.47	30.35±1.20	53.85±1.30	32.35±1.00
	SO ₄ (mg/mL)	294.07±4.76	10.26±0.01	1.69±0.01	3.83±0.01
	Turbidity(NTU)	87.86±3.00	11.00±0.02	5.54±0.03	13.69±0.01
	COD(mg O ₂ / L)	1760.00±1.26	1040.00±0.50	896.00±0.50	832.00±0.50
	BOD ₅ (ppm)	18.13±7.82	6.25±0.23	5.88±0.22	5.13±0.40

Key: Temp = Temperature, PO₄ = Phosphate, SO₄ = Sulfate, NH₃ = Ammonia, CaOCl₂ = Calcium hypochloride, mg/ L = Milligram per liter, ppm = part per million, AgNPs = Silver nanoparticles, COD = chemical oxygen demand, BOD₅ = Biological oxygen demand at Day 5.

Table 3C: Physicochemical effect of Ag-NPS on sample C Ukwaka River

Agent	Parameters	Treated (Min)			
		Untreated control	30	60	120
<i>C. papaya</i>	pH	7.11±3.46	8.69±0.01	8.71±0.01	8.72±0.01
	Temp. (°C)	26.10±7.89	28.30±0.20	28.30±0.20	28.30±0.20
	PO ₄ (mg/mL)	6.65±1.23	5.65±0.04	19.13±0.03	13.04±0.03
	NH ₃ (mg/mL)	37.01±6.43	43.85±0.23	29.85±0.24	45.35±0.26
	SO ₄ (mg/mL)	93.59±3.77	80.02±2.20	19.67±2.30	23.83±0.10
	Turbidity(NTU)	84.49±1.25	48.31±0.20	24.46±0.30	16.00±0.40
	COD(mg O ₂ /L)	1632.00±1.36	800.00±2.08	736.00±4.20	720.00±5.29
	BOD ₅ (ppm)	13.75±1.47	5.75±0.02	5.50±0.01	5.25±0.01
	CaOCl ₂	pH	7.11±3.46	8.92±0.01	8.82±0.01
Temp. (°C)		26.10±7.89	26.60±0.21	26.50±0.22	26.40±0.02
PO ₄ (mg/mL)		6.65±1.23	161.74±0.22	116.52±0.23	61.74±0.22
NH ₃ (mg/mL)		37.01±6.43	59.85±0.33	107.85±0.41	118.35±0.02
SO ₄ (mg/mL)		93.59±3.77	9.55±0.01	11.93±0.01	3.59±0.02
Turbidity(NTU)		84.49±1.25	8.31±0.03	7.27±0.01	3.62±0.01
COD(mg O ₂ /L)		1632.00±1.36	1150.00±1.00	1120.00±3.20	1056.00±3.00
BOD ₅ (ppm)		13.75±1.47	6.13±0.01	5.88±0.01	5.75±0.01

Key: Temp = Temperature, PO₄ = Phosphate, SO₄ = Sulfate, NH₃ = Ammonia, CaOCl₂ = Calcium hypochloride, mg/ L = Milligram per liter, ppm = part per million, AgNPs = Silver nanoparticles, COD = chemical oxygen demand, BOD₅ = Biological oxygen demand at Day 5.

Table 3D: Physicochemical effect of Ag-NPS on sample D Sacred Heart Waste Water Reservoir

Agent	Parameters	Treated (Min)			
		Untreated (Control)	30	60	120
<i>C. papaya</i>	pH	6.94±3.46	8.74±0.01	8.74±0.01	8.74±0.01
	Temp. (°C)	26.70±0.46	28.60±0.01	28.70±0.02	28.60±0.03
	PO ₄ (mg/mL)	7.00±1.35	8.69±0.03	6.69±0.04	11.74±0.02
	NH ₃ (mg/mL)	18.16±6.32	25.35±0.01	23.85±0.01	23.35±0.01
	SO ₄ (mg/mL)	26.69±4.63	28.12±0.01	22.40±0.01	21.57±0.01
	Turbidity(NTU)	1.02±2.17	5.54±0.01	9.46±0.01	1.00±3.06
	COD(mg O ₂ /L)	1712.00±1.68	720.00±4.01	656.00±4.02	576.00±3.02
	BOD ₅ (ppm)	14.25±6.32	5.13±0.01	5.00±0.02	4.88±0.02
	CaOCl ₂	pH	6.94±3.46	8.80±0.01	0.83±0.01
Temp. (°C)		26.70±0.46	26.40±0.08	26.40±0.12	26.40±0.24
PO ₄ (mg/mL)		6.97±1.35	130.00±0.83	24.78±0.04	55.65±0.04
NH ₃ (mg/mL)		18.16±6.32	43.35±0.09	36.85±5.62	37.85±5.12
SO ₄ (mg/mL)		26.69±4.63	2.40±0.25	6.46±0.11	8.36±1.12
Turbidity(NTU)		1.02±2.17	2.46±0.04	10.23±0.06	2.54±0.24
COD(mg O ₂ /L)		1712.00±1.68	688.00±1.53	656.00±1.63	544.00±1.76
BOD ₅ (ppm)		14.25±6.32	5.25±0.03	4.63±0.08	4.13±0.01

Key: Temp = Temperature, PO₄ = Phosphate, SO₄ = Sulfate, NH₃ = Ammonia, CaOCl₂ = Calcium hypochloride, mg/ L = Milligram per liter, ppm = part per million, AgNPs = Silver nanoparticles, COD = chemical oxygen demand, BOD₅ = Biological oxygen demand at Day 5.

Table 3E: Physicochemical effect of Ag-NPs on sample E Uiasi River

Agent	Parameters	Treated (Minutes)			
		Untreated control	30	60	120
<i>C. papaya</i>	pH	5.83±0.82	8.77±0.01	8.76±0.01	8.76±0.01
	Temp. (°C)	26.00±2.76	28.30±0.24	28.30±0.22	28.30±0.23
	PO ₄ (mg/mL)	6.01±2.14	16.69±0.23	23.04±0.01	29.57±0.36
	NH ₃ (mg/mL)	139.33±3.00	39.35±1.34	58.85±1.02	45.85±1.67
	SO ₄ (mg/mL)	74.19±4.36	8.24±0.01	17.64±3.86	16.69±0.38
	Turbidity(NTU)	2.31±0.94	67.92±0.12	71.77±0.37	106.00±1.15
	COD(mg O ₂ /L)	1632.00±0.871	720.00±4.16	656.00±3.51	576.00±3.05
	BOD ₅ (ppm)	17.00±4.50	7.13±0.01	7.00±0.01	6.88±0.01
	CaOCl ₂	pH	5.83±0.82	8.80±0.45	8.85±0.01
Temp. (°C)		26.00±2.76	26.40±0.23	26.30±0.26	26.30±0.27
PO ₄ (mg/mL)		6.01±2.14	251.74±0.53	27.39±0.87	125.22±7.30
NH ₃ (mg/mL)		139.33±3.00	100.35±0.28	97.85±0.99	129.85±0.24
SO ₄ (mg/mL)		74.19±4.36	2.10±0.01	2.88±0.02	4.07±0.24
Turbidity(NTU)		2.31±0.94	89.08±0.08	22.54±0.99	85.62±0.08
COD(mg O ₂ /L)		1632.00±0.87	800.00±2.62	800.00±7.64	736.00±2.48
BOD ₅ (ppm)		17.00±4.50	6.38±0.02	6.25±0.04	6.25±0.07

Key: Temp = Temperature, PO₄ = Phosphate, SO₄ = Sulfate, NH₃ = Ammonia, CaOCl₂ = Calcium hypochloride, mg/ L = Milligram per liter, ppm = part per million, AgNPs = Silver nanoparticles, COD = chemical oxygen demand, BOD₅ = Biological oxygen demand at Day 5.

CONCLUSION

In this study, it was observed that synthesis of silver nanoparticles using *C. papaya* was possible especially reduction of silver nitrate (AgNO₃) in nanoparticle size which was due to the presence of hydroxyl group. This *C. papaya* biosynthesized nanoparticles effectively treated the freshwater sources, improving physicochemical qualities, comparable to calcium hypochlorite. This silver nanoparticle showed promising and affordable bioremediation potential for polluted water.

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