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Research Paper

Comparative Study of Commercial and Synthesized Silver Nanoparticle-Loaded Filters for Antibacterial Performance of Water

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Abstract
This study aims to fabricate and optimize silver nanoparticle (AgNPs)-loaded filters for enhanced bacterial removal and water purification. Two types of silver were utilized: commercially available silver (Ag1) and laboratory-synthesized silver (Ag2), prepared via a redox displacement method. The synthesized nanoparticles were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), atomic force microscopy (AFM), and energy-dispersive X-ray spectroscopy (EDS), confirming their nanoscale size, crystalline structure, and elemental composition. Various types of filter papers, including membrane and cellulose-based filters, were prepared with and without silver nanoparticle loading. Structural modifications such as layer separation and adhesive incorporation were also investigated to evaluate their impact on filtration performance. The antibacterial activity of the prepared filters was assessed against *Escherichia coli* ATCC 25922 using the plate count method. The results demonstrated that AgNPs-loaded filters exhibited significantly enhanced antibacterial efficiency, achieving complete removal (100%) of *E. coli* in selected configurations, while unloaded filters showed lower removal efficiencies ranging from 53% to 68%. Water quality analysis revealed that total dissolved solids (TDS), electrical conductivity (EC), and pH remained within acceptable drinking water standards after filtration. Furthermore, atomic absorption spectroscopy (AAS) analysis confirmed that the concentration of silver released into the filtered water was within safe limits, indicating no potential risk to human health. Home-based application tests further demonstrated stable performance and consistent water quality under continuous operation. Overall, the developed AgNPs-loaded filters represent an effective, low-cost, and practical solution for water disinfection, particularly in regions lacking advanced water treatment infrastructure.

Keywords
Purify Water, Filter Paper, Silver-Loaded Filters, Bacterial Removal Efficiency, *Escherichia coli* ATCC 25922

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1. INTRODUCTION

Clean drinking water is one of the most fundamental human needs; however, water purification systems continue to face significant challenges due to increasing contamination from pathogenic microorganisms as well as organic and inorganic pollutants. Conventional treatment methods, including sedimentation, chlorination, and mechanical filtration, are widely used but often fail to completely eliminate microorganisms or may generate harmful byproducts that pose risks to public health (Zafar et al., 2026). Consequently, recent scientific research has focused on developing more efficient, sustainable, and environmentally friendly water purification technologies. Water contamination represents a major environmental and public health concern, as polluted water can serve as a transmission route for various pathogenic microorganisms, leading to gastrointestinal and other infectious diseases (Hussain et al., 2020).

Among emerging solutions, silver nanoparticles (AgNPs) have attracted considerable attention due to their unique physicochemical properties and strong antimicrobial activity. Their high surface-to-volume ratio enhances their interaction with bacterial cells, resulting in disruption of cell membranes, damage to proteins and nucleic acids, and ultimately bacterial inactivation or death (Dakal et al., 2016). Previous studies have demonstrated that incorporating AgNPs into filter media such as cellulose paper, membranes, and polymeric materials can significantly enhance bacterial removal efficiency by combining physical filtration with antimicrobial action (Dankovich and Gray, 2011). In particular, AgNPs-loaded paper filters have shown effective elimination of *Escherichia coli* within short contact times while maintaining stable performance over repeated usage cycles (Ahsan et al., 2022). *Escherichia coli* ATCC 25922 is widely used as an indicator organism for fecal contamination in water due to its prevalence in wastewater and its association with increased risk of intestinal infections (Tasic et al., 2022; Sharan et al., 2020).

Therefore, improving the removal efficiency of this microorganism is essential for ensuring safe drinking water, especially in regions lacking advanced centralized treatment facilities (Kamei and Soori, 2026). Filtration remains one of the most effective techniques for removing microorganisms from water, with its efficiency depending on factors such as filter material, pore size, number of layers, and structural characteristics.

The integration of silver nanoparticles into filtration systems has been shown to significantly enhance antimicrobial performance by inducing oxidative stress, disrupting metabolic pathways, and interfering with DNA replication in microbial cells (Ning et al., 2020). In this study, different types of paper-based filters loaded with silver nanoparticles were fabricated and evaluated. The removal efficiency of *E. coli* ATCC 25922, as well as the physicochemical properties of the filtered water-including total dissolved solids (TDS), electrical conductivity (EC), and overall safety-were systematically investigated. The aim of this work is to assess the antibacterial performance of the developed filters and explore their practical applicability in water purification systems. The novelty of this study lies in the fabrication and systematic evaluation of AgNPs-loaded filters using a comparative approach that includes different filter materials and structural modifications. Unlike previous studies that focus on a single material or preparation method, this work integrates both commercially available silver (Ag1) and laboratory-synthesized silver (Ag2). Additionally, it examines the effects of structural variations, such as layer separation and adhesive incorporation, on filtration performance. Furthermore, the study combines microbiological assessment with physicochemical water quality analysis, providing a comprehensive evaluation of filter efficiency and practical applicability.

2. EXPERIMENTAL SECTION

2.1 Materials and Synthesis of Silver Nanoparticles

A commercially available silver sample (denoted as Ag1) was used as a reference material for comparative analysis. The sample was subjected to preliminary characterization to evaluate its physicochemical properties. For comparison, a second silver sample (Ag2) was synthesized from silver nitrate ($AgNO_3$) via a redox displacement method. Initially, an appropriate amount of $AgNO_3$ was dissolved in distilled water to obtain a homogeneous aqueous solution. A copper wire was then immersed in the solution to induce the reduction of silver ions (Ag^+) and the subsequent precipitation of metallic silver (Ag°). Mild heating was applied to enhance the reaction kinetics and ensure complete reduction. The resulting silver precipitate was collected and thoroughly washed several times with distilled water to remove impurities and residual ions. After purification, the product was dried under controlled conditions. To improve crystallization and structural stability, the dried sample was subjected to sintering at 500 °C. Finally, the synthesized silver sample (Ag2) was characterized and systematically compared with the commercially obtained sample (Ag1) in terms of structural and physicochemical properties.

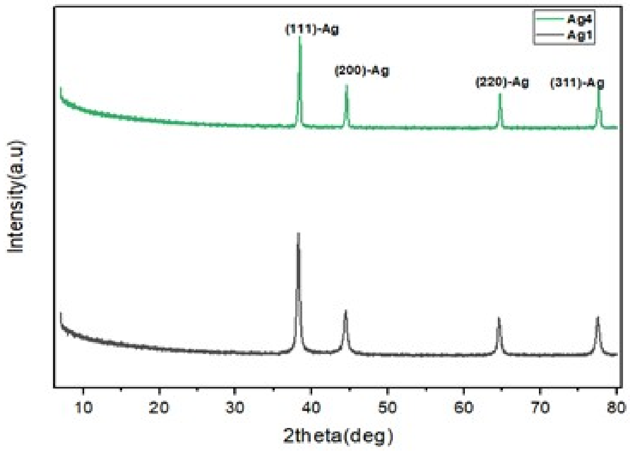


Figure 1. X-Ray Diffraction Pattern of Samples Ag1, Ag2

3. RESULT AND DISCUSSION

Figure 1, shows, the X-ray diffraction (XRD) patterns of Ag1 and Ag2 are presented in Figure 1. The diffraction peaks observed at 2θ values of 38.17°, 44.20°, 64.00°, and 77.32° correspond to the (111), (200), (220), and (311) crystallographic planes of face-centered cubic (FCC) silver, respectively. These results are in excellent agreement with standard reference data (ICDD cards No. 98-005-3761 and 98-060-4629), confirming the successful formation of crystalline silver in both samples. The dominant intensity of the (111) peak indicates a preferred crystallographic orientation, which is commonly associated with enhanced stability and growth direction in silver nanoparticles. Minor shifts in peak positions compared to standard values are attributed to lattice strain and structural defects introduced during synthesis (Shano et al., 2023). The calculated lattice parameters ($a = b = c \approx 4.088–5.545$ Å) confirm the cubic crystal structure ($\alpha = \beta = \gamma = 90^\circ$). Consistent with pure metallic silver (Klug and Alexander, 1974). Additionally, crystallite size analysis using the Scherrer equation revealed nanoscale dimensions, indicating successful formation of nanocrystalline silver. These results confirm that both Ag1 and Ag2 possess highly crystalline FCC structures with no impurity phases detected, demonstrating successful synthesis and structural stability.

The structural parameters of the synthesized and reference silver samples are summarized in Table 1. The X-ray diffraction data indicate that both Ag1 (standard) and Ag2 (experimental) exhibit characteristic reflections corresponding to the (111) crystallographic plane of face-centered cubic (FCC) silver at $2\theta \approx 38.20–38.36^\circ$. The interplanar spacing (d_{hkl}) values are consistent with standard silver data, confirming the formation of crystalline metallic silver.The lattice constants ($a = b = c \approx 4.088–4.0885$ Å) further confirm the cubic crystal structure of silver ($\alpha = \beta = \gamma = 90^\circ$), indicating high structural symmetry and phase purity in both samples. Crystallite size (D) was calculated using the Scherrer equation, and the results show nanoscale dimensions for both samples. Although slight variations in FWHM

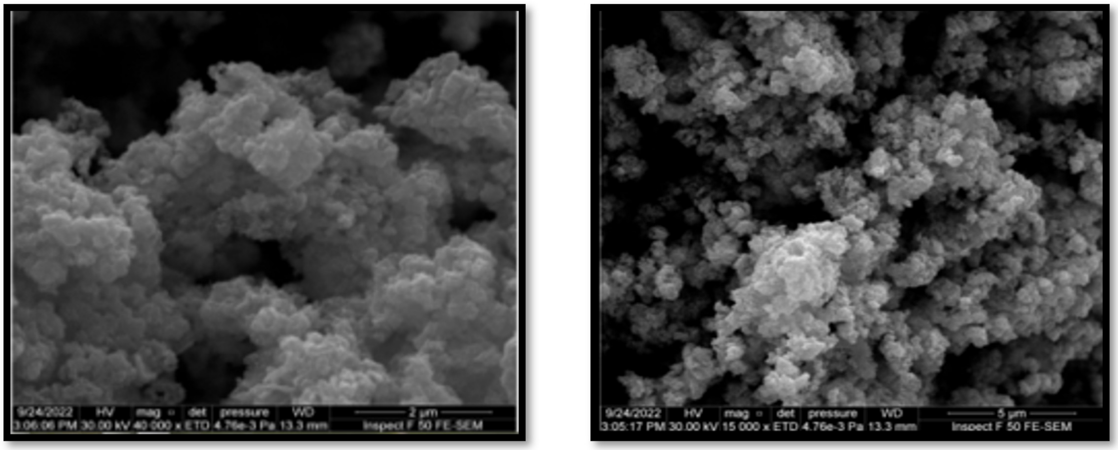


Figure 2. SEM Images of Sample Ag1

Table 1. Structural Properties of Silver

Sample	2θ (deg)	hkl	FWHM (deg)	d_{hkl} (Å)	D (nm)	Lattice Constant (a^o) (Å)	Lattice Constant (c^o) (Å)
Ag1 (Standard)	38.20	111	0.3577	2.35351	23.50	4.0880	4.0880
Ag2 (Experimental)	38.36	111	0.2363	2.34457	33.7	4.0885	4.0885

values were observed (0.3577° for Ag1 and 0.2363° for Ag2), the calculated crystallite size remains in the nanometer range, confirming successful synthesis of nanocrystalline silver. Minor differences in structural parameters between Ag1 and Ag2 can be attributed to variations in synthesis conditions, which influence nucleation and growth behavior. In particular, thermal treatment and precipitation conditions may enhance atomic mobility, allowing atoms to occupy energetically favorable lattice positions, which can promote grain growth and improve crystallinity (Sharma et al., 2009; Cullity and Stock, 2001). These results confirm that both samples exhibit a stable FCC crystal structure with high crystallinity and nanoscale particle size. The slight variations in crystallite size and lattice parameters are consistent with synthesis-dependent structural effects and do not affect the overall phase identity of silver. The SEM micrographs (Figures 2 and 3) reveal the surface morphology of Ag1 and Ag2 nanoparticles. Both samples exhibit predominantly spherical to quasi-spherical shapes with nanoscale dimensions. However, slight variations in particle size distribution and agglomeration behavior are observed between the two samples. Ag2 nanoparticles show a relatively more heterogeneous distribution, which can be attributed to the chemical reduction process and thermal treatment conditions (Goldstein et al., 2017; Egerton, 2005). In contrast, Ag1 exhibits more uniform particle distribution due to its commercial processing route. The SEM results confirm successful nanoparticle formation in both samples. The observed differences in morphology indicate that the synthesis method significantly influences particle size distribution, agglomeration behavior, and surface uniformity.

AFM images (Figures 4 and 5) provide detailed three-dimensional surface topology of Ag1 and Ag2 nanoparticles. The images confirm the presence of nanoscale structures with both isolated particles and aggregated clusters. The observed aggregation is attributed to strong interparticle van der Waals forces. Quantitative analysis revealed surface roughness values (Ra = 3.67 nm, RMS = 4.4 nm) and an average grain size of approximately 65.79 nm, indicating a relatively uniform nanoscale surface with limited aggregation (Binnig et al., 1986). The AFM results confirm that both samples maintain nanoscale morphology with acceptable surface uniformity. Slight aggregation does not compromise the overall nanostructure, indicating successful synthesis and stability of AgNPs.

The EDS spectra (Figures 6 and 7) confirm the elemental composition of the synthesized nanoparticles. The dominant peaks correspond to silver (Ag), verifying successful formation of Ag nanoparticles in both Ag1 and Ag2 samples. Minor oxygen peaks (~0.5 keV) are attributed to surface oxidation, which is commonly observed in silver nanoparticles exposed to air. Silicon peaks (~1.8 keV) originate from the silicon substrate used during measurement and do not represent intrinsic sample composition. The absence of unexpected elemental peaks confirms the purity of the synthesized nanoparticles. The presence of oxygen is limited to surface effects and does not affect the core structure or functionality of AgNPs.

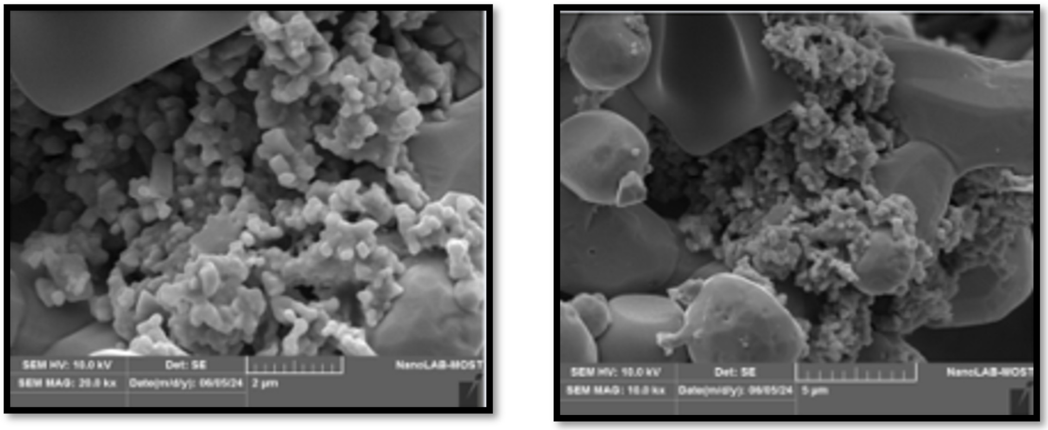


Figure 3. SEM Images of Sample Ag2

Table 2. Results of the Filter Papers and Indicates the Number of Bacteria and the Removal Percentage

Types	Description of Filter Paper	Bacterial Number	Removal Rate (%)
0.0	Factory filter paper without any additives	1×10^8	0.0
1	Factory filter paper containing silver particles Ag1	55×10^6	45
2	Factory filter paper containing silver particles dissolved in nitric acid	31×10^6	69
3	Factory filter paper containing Ag2	82×10^6	18
4	Factory filter paper + silver particles dissolved in nitric acid	18×10^6	82
5	Laboratory filter paper without any additives	77×10^6	23
6	Laboratory filter paper containing silver particles dissolved in nitric acid	6.6×10^7	34
7	Laboratory filter paper containing silver particles Ag1	2.1×10^7	79
8	Laboratory filter paper containing silver particles Ag2	1.3×10^7	87
9	Laboratory filter paper containing silver particles Ag2	1.1×10^7	89
10	Filter paper stripped without addition	0.8×10^7	92
15	Filter paper stripped middle layer + Ag1	1×10^6	99.9
16	Filter paper stripped first layer + Ag2	5×10^6	95
17	Filter paper stripped first layer glued with silicon + Ag1	8×10^6	92
18	Filter paper stripped first layer glued with silicon + Ag2	1.2×10^6	98.8
19	Filter paper stripped first layer glued with silicon + Ag1	1.1×10^6	98.9
20	Filter paper stripped first layer glued with silicon + Ag2	9×10^6	91

3.1 Filter Preparation and Performance Evaluation

In this study, two main types of filter media were employed: (i) a rolled multilayer membrane filter commonly used in household filtration systems, consisting of three structural layers, and (ii) circular cellulose filter papers with a diameter of 4.5 inches widely used in laboratory applications due to their high porosity and bacterial retention capacity. The filters were prepared under different configurations, including unmodified (without additives), silver-loaded (Ag1 and Ag2), and chemically modified systems. Structural modifications such as layer separation and the use of adhesive materials (e.g., silicone) were also introduced to investigate their influence on filtration efficiency. Silver nanoparticles were incorporated in two forms: commercially available silver (Ag1) and laboratory-synthesized silver (Ag2). All filtration processes were performed under sterile conditions to avoid external contamination. The prepared filters were classified as follows: A1:Membrane filter without silver, A2:Membrane filter with Ag1, A3:Membrane filter with Ag2, A4:Cellulose filter without silver, A5:Cellulose filter with Ag1, A6:Cellulose filter with Ag2, (Additional modified and layered configurations are presented in Table 4). A biological counting grid was used to ensure accurate quantification of bacterial colonies by dividing the agar surface into measurable sections, improving reproducibility and precision in colony counting (Deshmukh et al., 2020).

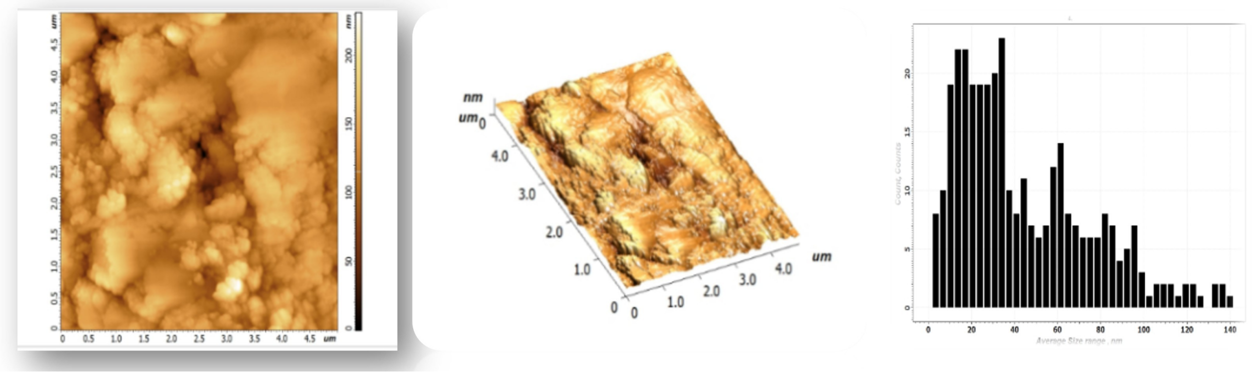


Figure 4. AFM Image of Sample Ag1, 2D, 3D, Particle Size Distribution

Table 3. TDS, EC, and Temperature Measurements of Water Filtered through Different Filter Papers

Water Output Number	ppm	EC MS/cm	°C	°F
0	2	4	35.3	96.8
1	227	451	34.4	94.2
2	370	336	34.0	93.5
3	372	744	34.0	93.5
4	396	782	35.1	95.5
5	336	665	34.8	95.0
6	812	606	36.2	97.3
7	299	515	35.9	96.8
8	583	168	35.8	96.8
9	407	794	35.1	95.1
10	125	249	34.3	94.2
15	168	185	35.2	95.3
16	40	77	35.0	95.1
17	70	145	33.3	92.3
18	93	193	34.2	94.1
19	60	115	34.2	93.9
20	54	121	33.8	93.2

3.2 Antibacterial Performance of Filters

Table 2, summarizes the antibacterial efficiency of the prepared filters against *Escherichia coli* ATCC 25922. The results demonstrate a clear dependence of bacterial removal efficiency on both silver incorporation and structural modification of the filters. Unmodified filters showed limited bacterial removal efficiency (0–34%), indicating that physical filtration alone is insufficient for complete bacterial elimination. In contrast, silver-loaded filters exhibited significantly improved performance, with removal efficiencies ranging from 45% to 92% depending on silver type, concentration, and filter structure. Notably, filters incorporating Ag2 demonstrated enhanced antibacterial activity compared to some Ag1-based configurations, suggesting that synthesis method and particle characteristics influence antimicrobial effectiveness. The highest removal efficiencies (up to 99.9%) were observed in structurally modified filters, particularly those with layer separation and silicone-assisted stabilization, indicating that increased contact time and improved nanoparticle retention significantly enhance bacterial inactivation (Madani and Rahimpour, 2005). These results confirm that silver nanoparticles play a crucial role in bacterial inactivation through membrane disruption and oxidative stress mechanisms. Additionally, structural modifications of the filter matrix significantly enhance bacterial retention and antimicrobial efficiency, demonstrating a synergistic effect between physical filtration and chemical disinfection.

Table 4. Effect of Silver Nanoparticle-Loaded Filter Papers on *Escherichia coli* ATCC

Treatment	Bacterial Number	Removal Rate (%)
Control	100×10^6	0.0
A1	47×10^6	53
A2	35×10^6	65
A3	32×10^6	68
A4	No growth	100
A5	No growth	100
A6	No growth	100

3.3 Water Quality Assessment

Table 3, presents the physicochemical properties of filtered water, including total dissolved solids (TDS), electrical conductivity (EC), and temperature. The results indicate variations in mineral content depending on the filter type and treatment conditions. Despite fluctuations in TDS and EC values, all measurements remained within acceptable ranges for potable water. The observed variations are attributed to differences in filter composition, silver loading, and adsorption of dissolved ions during filtration. The presence of silver nanoparticles did not negatively affect the overall water quality. Instead, the filters maintained stable physicochemical properties, confirming their suitability for safe water purification applications.

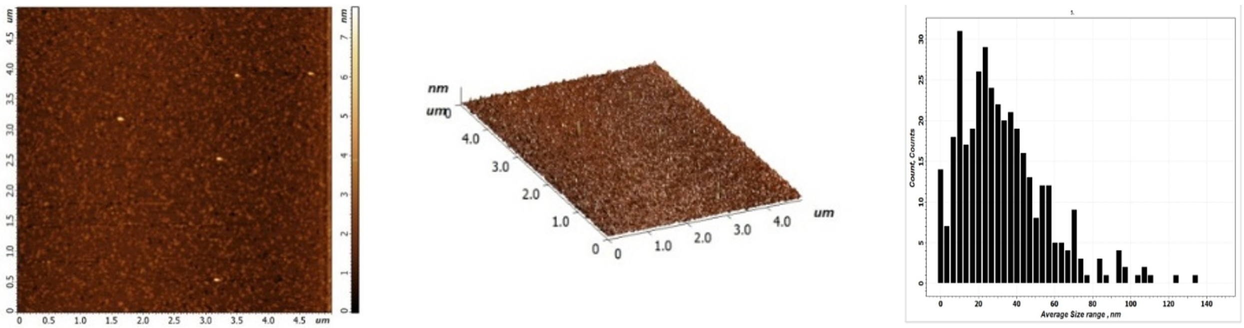


Figure 5. AFM Image of Sample Ag2 ,2D, 3D, Particle Size Distribution

3.4 Antibacterial Activity Against *E. coli* ATCC 25922

The antibacterial performance of the prepared filters was evaluated using the plate casting method.

Table 5. Silver Concentration (ppm) in Filtered Distilled Water and Tap Water Samples

Sample	ppm	Abs	BG
Control Distilled water	0.4721	0.0188	0.0017
A1	4.0345	0.5560	0.0020
A2	1.7785	0.2158	0.0013
A3	12.7109	1.8644	0.0183
A4	3.9350	0.5410	0.0028
A5	1.4344	0.1639	0.0017
A6	16.6724	2.4618	0.0834
A7	9.3309	1.3547	0.0066
A8	1.7129	0.2059	0.0024
A9	1.7407	0.2101	0.0023
A10	0.7619	0.0625	0.0018
Liquid Tap Water	0.5046	0.0237	0.0018

3.5 Preparation of Bacterial Suspension

Escherichia coli ATCC 25922 was activated by culturing in Brain Heart Infusion (BHI) broth for 24 h at 37 °C under continuous shaking. The bacterial suspension was then adjusted to a concentration of 1×10^8 cells/Ml (Madani, 1999).

3.6 Plate Casting and Incubation

One milliliter of the filtrate was mixed with 25 mL of molten Mueller–Hinton agar and allowed to solidify at room temperature. The plates were then incubated at 37 °C for 24 h. After incubation, the bacterial colonies formed on the plates were counted to determine the effectiveness of each filter.

3.7 Determination of Inhibition Percentage

The antibacterial efficiency of the filters was calculated using the following equation (Baird et al., 2017):

$$\text{Inhibition (\%)} = 100 - \left(\frac{\text{Number of test colonies}}{\text{Number of control colonies}} \times 100 \right)$$

In example A1 is $100 - 47/100 \times 100\% = 53$.

The results presented in Table 3 demonstrate a clear variation in antibacterial efficiency among the different filter configurations against *Escherichia coli* ATCC 25922. The control sample showed full bacterial growth (100×10^6 CFU), confirming the absence of any antibacterial effect without treatment. Filters A1–A3 exhibited partial bacterial reduction, with removal efficiencies ranging from 53% to 68%. This indicates that these filters possess moderate antibacterial activity, which can be attributed to the presence of silver nanoparticles combined with physical filtration mechanisms. The partial inhibition suggests that bacterial cells were either retained by the filter structure or inactivated through interaction with silver ions released from the filter matrix. In contrast, filters A4–A6 demonstrated complete inhibition of bacterial growth (100% removal), with no detectable colonies observed after incubation. This result indicates a strong synergistic effect between filter structure and silver nanoparticle incorporation, leading to full bacterial inactivation. The absence of bacterial colonies confirms that these filter configurations are highly effective in eliminating *E. coli* under the tested conditions. From a microbiological perspective, *E. coli* ATCC 25922 is widely used as an indicator organism for fecal contamination in water systems. Its presence typically suggests contamination with sewage or other pathogenic microorganisms, making its removal a critical indicator of water safety. Therefore, the high removal efficiency observed in this study demonstrates the strong potential of silver nanoparticle-loaded filters for improving microbiological water quality and reducing health risks associated with contaminated water sources (Nowicki et al., 2021).

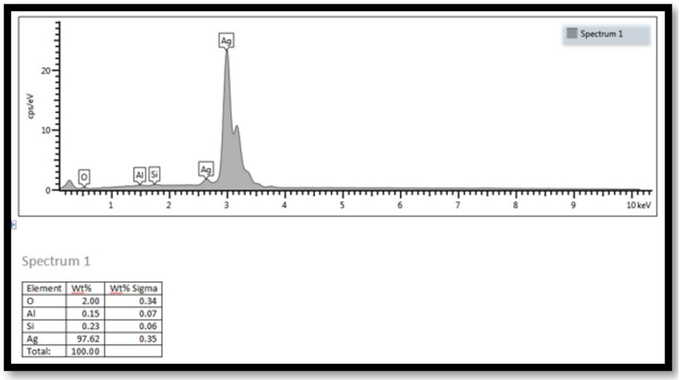
From the Figure 9, and Table 3, it appears that the filter is A1 The removal rate is (53%), the A2 filter has a removal rate of 65%, while the third filter A3 has a removal rate of (68%) . This indicates that part of the bacteria passes through, and because of the silver present, part of the bacteria is killed or inhibited. As for the last three filters, A4, A5, and A6, there is no growth of bacteria, and this indicates that the removal rate is 100% and that bacteria do not pass through the filter (Ahsan et al., 2022).

3.8 Filtration Procedure and AAS Analysis

Water samples containing the bacterial suspension were passed through the prepared filter papers under sterile conditions, us-

Table 6. Atomic Screening of Circular Filters Loaded with Ag1 via the Dipping Method

Sample	Type of Filter Added Ag1	ppm	Abs	BG
C1	Tap Water with Silver	0.5729	0.0340	0.0004
C2	Fibre Class with Vydrin Rubber	0.9350	0.0886	0.0010
C3	Fibre Class with Silicone	1.4111	0.1604	0.0015
C4	Waxed Fibre with Silicone	2.0809	0.2614	0.0021
C5	Waxed Fibre with Rubber Vedrine	0.3448	-0.0004	-0.0004
C6	Membrane Filter Paper with Vedrin Rubber	0.4430	0.0144	-0.0003
C7	Membrane Filter Paper with Silicone	0.3442	-0.0005	-0.0003
C8	Plain Filter Paper	0.3495	0.0003	-0.0006
C9	Tap Water Control	0.3501	0.0004	-0.0006



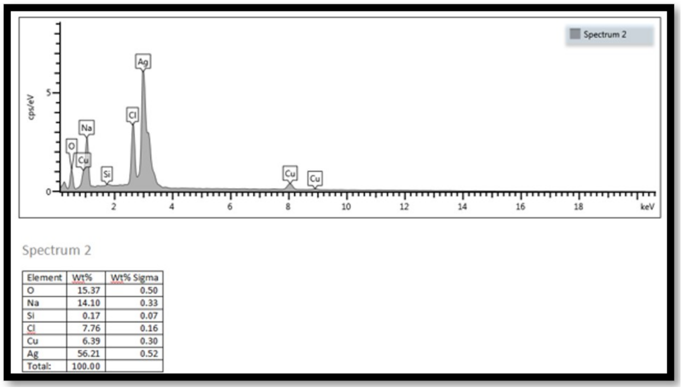
Spectrum 1

Element	Wt%	Wt% Sigma
O	2.00	0.34
Al	0.15	0.07
Si	0.23	0.06
Ag	97.62	0.35
Total:	100.00	

Figure 6. EDS Spectra Analysis of Sample Ag1

ing different structural and compositional configurations. The resulting filtrates were collected and subjected to further microbiological and physicochemical analyses. Atomic Absorption Spectroscopy (AAS) is a widely used analytical technique for the quantitative determination of metallic elements at trace levels. Based on the principles established by Kirchhoff and Bunsen, each element absorbs light at specific characteristic wavelengths (resonance lines), enabling precise identification and quantification (Skoog et al., 1998). AAS is considered a rapid, selective, and highly sensitive method for detecting approximately 80 elements in solution with minimal spectral interference (Welz and Sperling, 2008). As in Table 5.

Among the treated samples, A1 exhibited a marked increase in salt concentration, reaching 4.0345 ppm. This increase is associated with the incorporation of silver nanoparticles and dissolved ionic species released during the preparation of the first group of samples. In addition, samples prepared through dispersion using magnetic stirring for one hour showed higher measured concentrations, which may be attributed to improved dissolution and uniform distribution of nanoparticles in the aqueous medium (American Public Health Association, 1926). Concentrations, indicating that sample preparation strongly influences the measured ionic content. Sample A9, which was diluted with distilled water, and sample A10, which was directly filtered, also exhibited reduced ppm values, further confirming the effect of dilution and filtration conditions on ionic concentration. Tap water and distilled water showed only minor differences in total dissolved solids (approximately 1 ppm), confirming consistency in baseline water quality (Kumar et al., 2017). Overall, the results demonstrate that the presence of silver nanoparticles and associated processing steps can slightly increase total dissolved solids (TDS) in water. However, all recorded values remain within acceptable drinking water limits, indicating that the treated water maintains its safety for potential consumption. The variation in ppm values among samples is primarily attributed to differences in preparation method, dispersion time, and filter interaction rather than contamination. This confirms that AAS analysis is highly sensitive to sample handling conditions and must be carefully standardized for accurate interpretation.



Spectrum 2

Element	Wt%	Wt% Sigma
O	15.37	0.50
Na	14.10	0.33
Si	0.17	0.07
Cl	7.76	0.16
Cu	6.39	0.30
Ag	56.21	0.52
Total:	100.00	

Figure 7. EDS Spectra Analysis of Sample Ag2

Table 6, presents the silver concentration (ppm) in circular filters loaded with Ag1 using the dipping method, as determined by Atomic Absorption Spectroscopy (AAS). The results demonstrate that silver incorporation varies significantly depending on the type of filter substrate and the surface modification applied. The AAS results indicate that silver loading efficiency is strongly influenced by both the structural type of the filter and the surface modification technique. Filters treated with silicone and wax (particularly C3 and C4) exhibited higher silver retention, reaching up to 2.0809 ppm. This increase is attributed to improved surface adhesion and enhanced binding capacity of

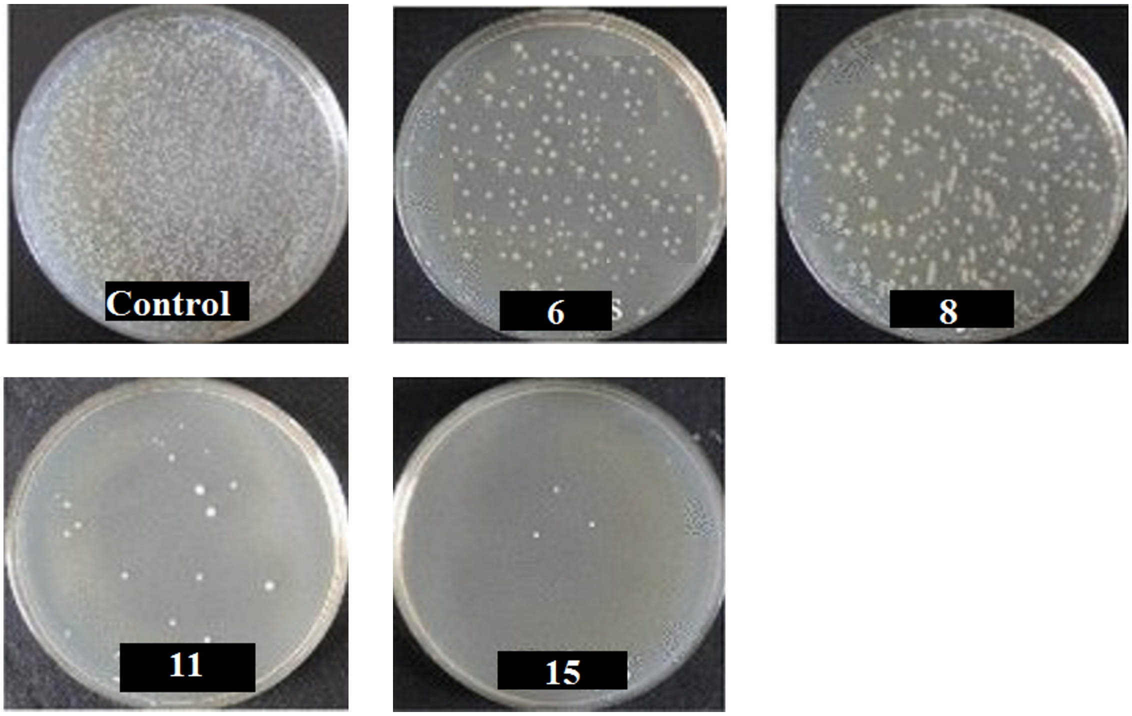


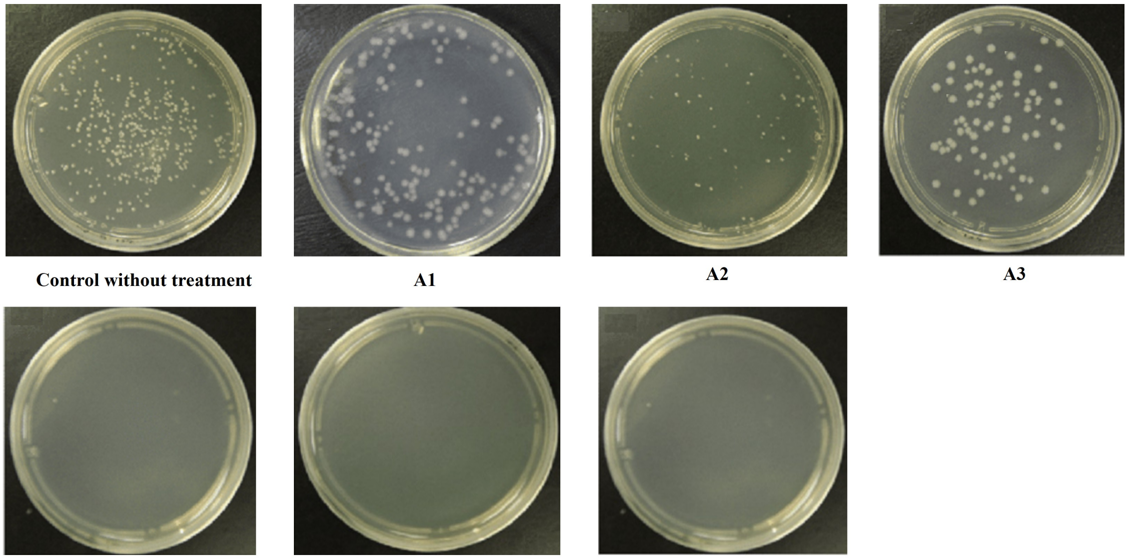
Figure 8. Effect of Silver Nanoparticles on *Escherichia coli* ATCC 25922 Growth under Different Filtration Conditions

these coatings, which facilitate better immobilization of silver nanoparticles on the filter matrix. In contrast, plain filter paper and membrane-based configurations (C7 and C8) showed relatively low silver concentrations, suggesting limited adsorption capacity without surface modification. Negative or near-zero values in some background-corrected readings are associated with instrumental baseline fluctuations and do not indicate actual negative concentrations. The tap water control (C9) exhibited minimal silver content, confirming that contamination during handling was negligible and that the dipping method is reliable for controlled silver incorporation (American Public Health Association, 1926; Rai et al., 2009). Overall, the findings confirm that surface engineering plays a critical role in enhancing nanoparticle loading efficiency. Coating materials such as silicone and wax improve the interaction between silver nanoparticles and filter substrates, leading to higher retention stability. This is particularly important for long-term antimicrobial performance, as higher silver retention is directly associated with sustained antibacterial activity.

A home-based experimental setup was conducted to evaluate the physicochemical properties of filtered water using a portable TDS meter. The parameters measured included total dissolved solids (TDS), electrical conductivity (EC), pH, and temperature, as shown in Table 7. A TDS meter indirectly estimates dissolved ion concentration by measuring electrical conductivity; higher EC values correspond to increased levels of dissolved salts such as calcium, magnesium, and sodium, which influence water taste, hardness, and overall quality (Adjovu et al., 2023). The results show moderate variations in TDS and EC values across different filter configurations. Samples C3 and C6 exhibited relatively higher TDS values, indicating increased mineral or ionic content, while C2 showed the lowest TDS level, suggesting more effective removal or reduced ion release from the filter material. The pH values of all samples ranged from slightly neutral to mildly alkaline (7.71–8.42), indicating that the filtration process did not significantly alter water acidity. Temperature variations were minimal and reflect only environmental conditions during measurement rather than filter performance (Lech et al., 2016). These findings confirm that the incorporation of silver nanoparticles and different structural modifications do not negatively affect the physicochemical stability of water. All measured parameters remain within acceptable drinking water standards, indicating that the developed filters maintain both microbiological safety and chemical stability. The observed variations in TDS and EC are primarily related to differences in filter composition and surface treatments rather than contamination, demonstrating that the system is suitable for practical household water purification applications.

3.9 Instrument and Equipment Used

Several laboratory instruments and equipment were employed to evaluate the performance of silver nanoparticle-loaded filters in bacterial removal and water quality assessment. The main instruments and their functions are summarized as follows: Colony Counting System. A colony counting system was used to quantify bacterial colonies grown on agar plates after filtration. This system enabled accurate determination of bacterial inhibition percentages for each filter. Automated counting systems improve



Control without treatment **A1** **A2** **A3**

A4 **A5** **A6**

Figure 9. Colony Count of *Escherichia coli* ATCC 25922 Exposed to Different Concentration of Ag and Filtration Conditions

Table 7. PPM of Dissolved Salts of the Water Produced by the Filters that was Tested at Home in a TDS Device

Filter	PPM	MS\CM	C^0	F	PH
C1	350	745	20.5	68.7	7.71
C2	261	734	23.0	73.5	7.82
C3	381	765	18.4	65.4	8.00
C4	369	749	22.5	72.8	8.03
C5	354	707	20.5	69.0	8.42
C6	376	748	19.3	67.1	7.90

reproducibility and minimize human error in microbiological analysis (American Public Health Association, 1926). Electrical Conductivity (EC) and Total Dissolved Solids (TDS) meters were used to measure ionic content in water (μS/cm and ppm, respectively). These parameters are essential indicators of water quality and filter efficiency in removing dissolved ions and contaminants. A digital pH meter was used to measure the acidity or alkalinity of water samples before and after filtration. Variations in pH may reflect interactions between silver nanoparticles, filter materials, and water chemistry (World Health Organization, 2011). AAS was used to determine the concentration of silver and other trace metals at ppm levels. This technique ensures that the filtered water remains within safe limits for human consumption and allows precise evaluation of nanoparticle leaching behavior (Skoog et al., 1998). Incubators were used to maintain bacterial cultures at 37 °C for 24 h, providing optimal conditions for microbial growth and enabling accurate assessment of antibacterial activity of the filters (Cappuccino and Sherman, 2011). Thermometers and digital temperature sensors (°C/°F) were used to monitor and maintain stable experimental conditions during filtration and analysis, ensuring data reliability. Additional laboratory tools, including analytical balances, test tubes, Petri dishes, and sterile containers, were used for sample preparation, filtration procedures, and microbiological analysis.

4. CONCLUSIONS

The present study successfully demonstrated the fabrication and optimization of silver nanoparticle (AgNPs)-loaded filters for efficient bacterial removal and water purification. The incorporation of AgNPs significantly enhanced the antibacterial performance of the filters, achieving complete removal (100%) of *Escherichia coli* ATCC 25922 in optimized configurations, compared to lower removal efficiencies (53–68%) observed in unloaded or partially loaded filters. Characterization analyses (XRD, SEM, AFM, and EDS) confirmed the successful synthesis of silver nanoparticles with nanoscale dimensions and suitable physicochemical properties, which contributed to their high antimicrobial activity. The results also revealed that both the type of filter material and structural modifications, such as layer separation and adhesive incorporation, play a critical role in improving filtration efficiency. Water quality assessment indicated that total dissolved solids (TDS), electrical conductivity (EC), and pH values remained within acceptable limits for drinking water after filtration. In addition, atomic absorption spectroscopy (AAS) confirmed that the concentration of silver released into the filtered water was within safe limits, ensuring its suitability for human consumption. Furthermore, the home-based experiments demonstrated stable performance and consistent water quality during continuous operation. Overall, the developed AgNPs-loaded filters represent an effective, low-cost, and practical solution for water purification, particularly in areas lacking advanced treatment systems.

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