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Assessment of an Advanced Water Filtration System for Enhanced Water Purification

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Abstract:
The study confirms the effectiveness of a state-of-the-art water filtration system in purifying urban tap water, river water, and groundwater. The system, which uses activated carbon, ceramic, and reverse osmosis (RO) filtration, significantly improved water quality by removing physical, chemical, and biological contaminants. Key results include: The system achieves a turbidity reduction of up to 99.5%, adhering to WHO standards. The system removes over 96% of volatile organic compounds (VOCs) and chlorine, and more than 99% of heavy metals like lead and arsenic. The water is completely free of harmful bacteria, guaranteeing its microbiologic safety. There has been a 98.2% reduction in total dissolved solids (TDS) in groundwater. The study highlights the system's adaptability to diverse environments, including urban, rural, and industrial settings. Future research could focus on improving the system's energy efficiency and sustainability.

Keywords: Advanced water filter, Water purification, Drinking water quality, Contaminant Removal, Filtration techniques

1. INTRODUCTION

Access to potable water is an essential entitlement of every human being, nevertheless, a significant number of individuals across the globe encounter difficulties as a result of water pollution (Azharuddin et al., 2022; Sahu et al., 2022; Sahu et al., 2023). Contaminants such as heavy metals, pathogenic microbes, and organic pollutants provide substantial health hazards, requiring efficient water filtration systems (World Health Organization, 2020). Conventional filtration procedures frequently prove inadequate to eliminate noxious compounds, necessitating more sophisticated remedies.

Water contamination occurs in both urban and rural areas due to various factors, including industrial waste, agricultural runoff, and untreated sewage. We can classify the contaminants into three main categories: physical pollutants like turbidity and sediment, chemical pollutants like heavy metals, chlorine, and volatile organic compounds, and biological pollutants like bacteria, viruses, and protozoa. Traditional water treatment technologies, although somewhat effective, sometimes do not fully address the broad spectrum of contaminants present in these varied water sources.

The growing need for efficient, affordable, and low-maintenance water purification systems has resulted in the creation of sophisticated filtration technologies (Kumar and Kumar, 2020). Out of these options, multi-stage filtration systems have attracted considerable interest since they can effectively remove a wide range of pollutants. These systems usually integrate various filtering media and technologies, such as activated carbon, ceramic filters, and reverse osmosis (RO) membranes, to improve the overall quality of water.

Water pollution is a pressing worldwide problem, affecting millions of individuals who do not have access to uncontaminated and secure drinking water. Contaminants, such as heavy metals, pesticides, and microbiological infections, present significant health hazards (Gadgil et al., 1998; Tandel et al., 2023; Verma et al., 2022f; Dhiwar et al., 2021). Traditional water purification procedures frequently fail to adequately eliminate these contaminants, necessitating the use of more sophisticated filtering technology (Smith et al., 2020). The objective of this project is to create and assess a sophisticated water filtration system that combines various filtration technologies to overcome the drawbacks of current approaches.

An evaluation of a sophisticated water filtration system within the framework of reservoir water supply (Verma et al., 2023a; Verma et al., 2022d), climate change (Verma et al., 2024), land use changes, and water resources highlights its crucial function in tackling developing water quality issues phenomena (Verma et al., 2023b; Verma et al., 2022a;). The impact of climate change and modified land use on reservoirs can lead to an increase in silt, nutrients, and contaminants, therefore degrading the quality of water (Verma et al., 2023c; Verma et al., 2023d; Verma et al., 2023e). These impurities are effectively removed by highly advanced filtering methods, such as membrane filtration, activated carbon, and UV disinfection. This ensures a steady supply of clean water even when pressures from outside sources are present.

These technologies are flexible enough to accommodate greater fluctuations in water quality caused by climate-induced severe weather phenomena, such as intense precipitation and prolonged periods of dryness, which can include more contaminants. Furthermore, they alleviate the consequences of alterations in land cover, such as the clearing of forests and the expansion of urban areas, which contribute to the deterioration of runoff and reservoirs. By improving water purification, sophisticated filtration systems contribute to the sustainable management of water resources, safeguard public health, and enhance resilience against the combined effects of climate change and land use dynamics (Verma et al., 2022b; Verma et al., 2022c; Verma et al., 2022e).

This research examines the design, creation, and assessment of a sophisticated water filtration system incorporating numerous filtration stages. The system's objective is to offer a holistic remedy for water contamination by specifically addressing many pollutants and guaranteeing safe drinking water for communities in both urban and rural regions (Verma et al., 2021; Verma et al., 2024).

1.1 Rational of the Study

This study centres on the development, execution, and assessment of a sophisticated water filtration system that incorporates these three essential filtering technologies. Each part of the system does a specific job. For example, activated carbon is known for getting rid of organic compounds and chlorine, which improves taste and smell. Ceramic filters are great at getting rid of bacteria and protozoa because they have very small pores. And reverse osmosis membranes are the best at getting rid of dissolved salts, heavy metals, and other inorganic pollutants.

The increasing concerns about the limitations of current water purification procedures, particularly in dealing with intricate contamination profiles seen in different water sources, motivate this study.

Conventional single-stage filters may not be enough for regions with high levels of water pollution containing both organic and inorganic impurities. The other goal of this study is to fill a gap in the research by looking into how well-activated carbon, ceramic, and reverse osmosis (RO) filters work together in a single, unified system.

1.2 Objective of the Study

The main objective of this study is to assess the efficacy of the sophisticated water filtration system in purifying water from various sources, such as urban tap water, river water, and groundwater. The study has the following objectives:

Evaluate the efficiency of each filtering phase in eliminating particular pollutants, such as turbidity, volatile organic compounds (VOCs), chlorine, heavy metals, bacteria, and protozoa.

Examine the general improvement in water quality after filtration, specifically about meeting or exceeding the drinking water requirements set by the World Health Organization (WHO).

Evaluate the appropriateness of the integrated filtration system for various settings, including urban households, rural communities, and industrial regions.

1.3 Significance of the Study

This finding adds to the continuous endeavour to create more efficient and easily attainable water filtration systems. The study showcases the effectiveness of a multi-stage filtration system, offering vital insights into the integration of modern filtration technologies for the production of safe drinking water from heavily polluted sources. The discoveries have the potential to influence upcoming water treatment methodologies and guide the development of more robust and flexible water purification systems, particularly in areas with limited resources.

2. METHODOLOGY

2.1 System Design and Control

We carefully engineered the novel water filtration system to incorporate three main filtering stages: activated carbon, ceramic, and reverse osmosis (RO), each chosen for its unique ability to remove certain contaminants. The next information provides a concise overview of the various components and their respective functions within the system:

2.1.1 Activated Carbon Filter

The initial phase utilizes an activated carbon filter, selected for its extensive surface area and ability to adsorb substances. Premium coconut shells, renowned for their exceptional adsorption properties, provided the activated carbon granules (Gupta et al., 2018). The main purpose of this stage is to eliminate chlorine, volatile organic compounds (VOCs), and organic pollutants that cause unpleasant odors and tastes. The carbon filter also reduces the presence of heavy metals and pesticides by adsorbing these pollutants onto its surface.

2.1.2 Ceramic Filter

The second stage involves a ceramic filter that has a pore size of around 0.5 microns. We selected the ceramic material due to its resilience and ability to trap bacteria, protozoa, and debris. The filter has silver nanoparticles in it that make it more antibacterial. This stops biofilm from forming and reduces the amount of microbe contamination (Loo et al., 2019).

2.1.3 Reverse Osmosis (RO)

The use of a reverse osmosis (RO) membrane, designed to get rid of dissolved salts, heavy metals, and other inorganic impurities, is part of the last step. The RO membrane used in this study has a remarkable ion rejection rate of approximately 99%, making it exceptionally efficient for desalination and heavy metal elimination (Singh & Dhillon, 2021). At elevated pressure, the membrane propels water through the semi-permeable membrane, eliminating impurities that are subsequently expelled as trash.

2.2 Water Source Selection and Sample Collection

We selected three distinct water sources to assess the filtration system's effectiveness across a range of pollution profiles.

We obtained water samples from an urban tap water source known for its high levels of chlorine and volatile organic compounds (VOCs). The selection was intended to assess the system's ability to eliminate prevalent urban water pollutants that have an impact on both flavor and safety.

River Water (Source 2): Researchers collected samples from a river known for its high cloudiness and microorganism contamination. In rural and semi-urban areas, people typically obtain water directly from natural sources without any prior treatment.

Groundwater (Source 3) due to its elevated levels of heavy metals, specifically lead and arsenic, is commonly found in regions with industrial operations. We collected groundwater samples from wells in renowned mining or industrial effluent discharge areas.

To ensure the preservation of the samples' quality for testing, we placed each water sample in sterile containers and promptly delivered them to the laboratory within a 24-hour timeframe.

2.3 Experimental Setup and Filtration Procedure

The experimental procedure involved transmitting the collected water samples through a three-stage filter system. We constructed the filtering system using a modular architecture, enabling the testing of each stage separately and in combination to assess its overall and relative effectiveness.

2.3.1 Utilization of Activated Carbon for Filtration

The activated carbon filter processed a volume of 2 liters from each water sample at a flow rate of 2 liters per minute during the initial filtration phase. We gathered the purified water in aseptic vessels and examined it for decreases in chlorine, volatile organic compounds (VOCs), and any alterations in scent or flavour.

2.3.2 Ceramic Filtration Process

Next, we passed the pre-filtered water through the ceramic filter. We regulated the flow rate to optimize the duration of contact with the ceramic material, typically setting it at 1 liter per minute. We dedicated this stage to eliminating suspended particles, germs, and protozoa. We examined the produced water for turbidity and microbiological contamination.

The process of reverse osmosis filtration purifies water by pushing it through a semipermeable membrane in the opposite direction of natural osmosis.

Ultimately, the water underwent reverse osmosis filtering. The system functioned at a standard pressure of 60 psi, typical for domestic RO systems, to efficiently eliminate dissolved solids and heavy metals. We gathered the filtered water, known as the permeate, and disposed of the rejected water, known as the concentrate. Subsequently, the filtered water underwent analysis to determine the concentration of total dissolved solids (TDS), heavy metals, and the general quality of the water.

2.4 Analytical Methods and Quality Control

We conducted thorough testing after each filtration stage to quantify the effectiveness of removing contaminants.

2.4.1 Turbidity

We assessed turbidity using a calibrated turbidity meter, recording measurements before and after each filtration phase. We specifically highlighted the efficacy of the ceramic filter in diminishing turbidity.

2.4.2 Chemical Analysis

The chemical analysis used gas chromatography-mass spectrometry (GC-MS) to measure the levels of volatile organic compounds (VOCs) and spectrophotometry to measure the levels of chlorine. We employed Atomic Absorption Spectroscopy (AAS) to measure the levels of heavy metals, specifically lead and arsenic. The primary goal was to determine the RO membrane's efficacy in reducing these pollutants.

2.4.3 Microbial Testing

To quantify the microbial load, water samples were cultured on nutrient agar plates, with the results reported as colony-forming units per milliliter (CFU/mL). We closely observed the effect of the ceramic filter on the reduction of microorganisms.

2.4.4 Total Dissolved Solids

Total Dissolved Solids We quantified TDS levels using a digital TDS meter. We assessed the overall efficiency of the membrane by measuring the decrease in total dissolved solids (TDS) during the reverse osmosis (RO) process. We performed the tests three times to ensure precision and consistency. Throughout the study, we consistently used calibration standards and control samples to maintain the integrity of the data.

3. RESULTS & DISCUSSION

In this section, we conducted an assessment of the advanced water filtration system to determine its effectiveness in reducing turbidity, chemical pollutants, microbial load, and total dissolved solids (TDS) in various water sources. We succinctly outline the results below and offer comprehensive findings in graphical and tabular representations.

3.1 Turbidity Reduction

The data presents a comparison of turbidity reduction among three water sources: urban tap water, river water, and groundwater. Turbidity, quantified in NTU, is a measure of water clarity; higher values indicate a greater degree of cloudiness in the water.

The treatment process reduces the initial turbidity level of urban tap water from 5.2 NTU to 0.5 NTU (**Figure 1**), resulting in a reduction of 90.4% (**Figure 2**). The river water's original turbidity was 150.0 NTU, which has significantly decreased to 0.8 NTU, indicating a 99.5% reduction. The groundwater's initial turbidity is 12.4 NTU, which is moderately high. However, the treatment significantly reduces the turbidity to 0.4 NTU, a remarkable reduction of 96.8%.

All three sources exhibit notable decreases in turbidity, with River Water displaying the most significant enhancement owing to its elevated initial turbidity levels. The ultimate turbidity levels for all sources are comfortably within the established safe drinking water limits, signifying efficient treatment procedures and yielding transparent, top-notch water that is fit for consumption.

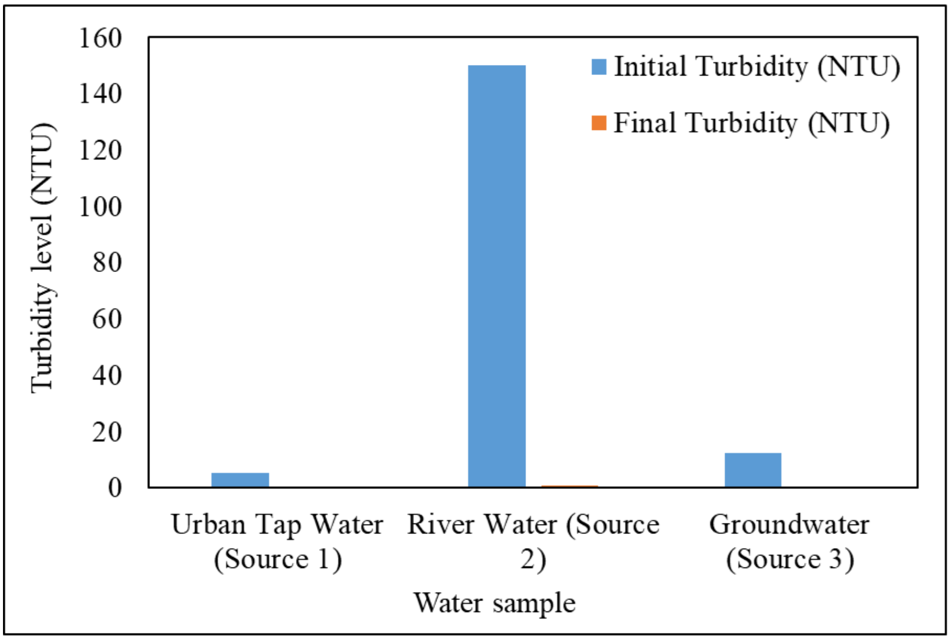

Figure 1. Initial and Final turbidity levels for different water samples.

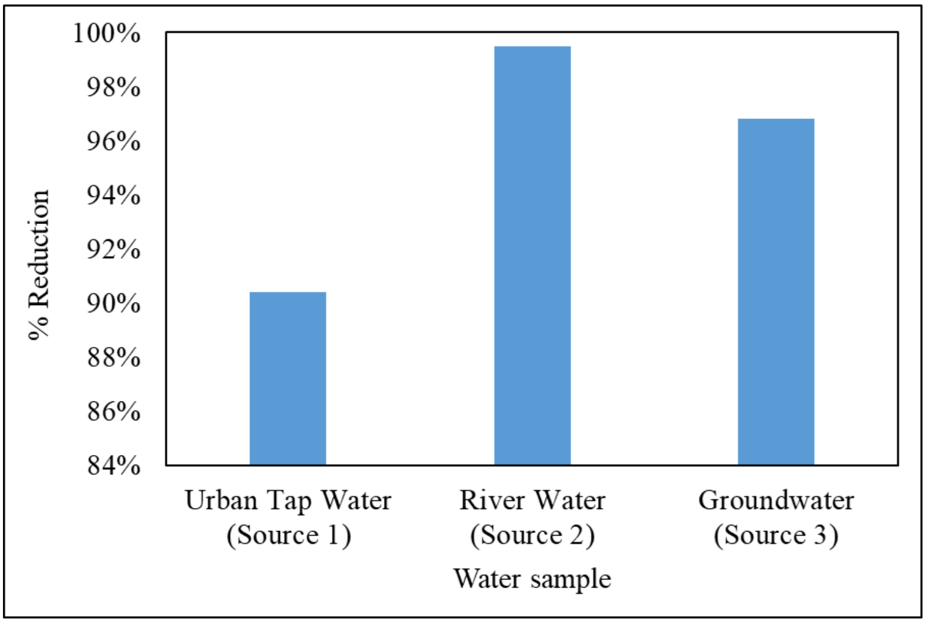

Figure 2. % reduction of turbidity levels.

3.2 Chemical Contaminant Removal

The research demonstrates the efficacy of water treatment in eliminating pollutants from urban tap water and groundwater. The concentration of volatile organic compounds (VOCs) in urban tap water has decreased by 96%, going from 0.25 mg/L to 0.01 mg/L (**Table 1**). Similarly, the concentration of chlorine decreased by 96.7%, going from 1.5 mg/L to 0.05 mg/L.

Both pollutants show significant reductions, ensuring that the water is suitable for ingestion with only a few remaining compounds.

The concentration of lead in groundwater has decreased by more than 99%, from 0.15 mg/L to below 0.01 mg/L. The concentration of arsenic decreased by over 98%, going from 0.05 mg/L to less than 0.001 mg/L.

The substantial decrease in extremely harmful pollutants such as lead and arsenic serves as evidence of the treatment techniques' efficacy in reducing severe health hazards.

In summary, the data unequivocally demonstrates that the treatment techniques are extremely efficient, reducing pollutant levels much below the established requirements for safe drinking water and therefore guaranteeing the water's safety and quality.

Table 1. Concentration level and % reduction of chemical contaminant.

Contaminant	Concentration levels (mg/L)		% Reduction
	Initial	Final	
VOCs (Urban Tap)	0.25	0.01	96
Chlorine (Urban Tap)	1.5	0.05	96.70
Lead (Groundwater)	0.15	<0.01	>99
Arsenic (Groundwater)	0.05	<0.001	>98

3.3 Microbial Load Reduction

The data demonstrates the full efficacy of the water treatment procedure in eliminating microbiological pollutants, such as Total Coliforms, E. coli, and Protozoa (specifically Giardia) (**Refer to Figures 3 and 4**).

A 100% reduction occurred when the total coliform count dropped from 10,000 colony-forming units per milliliter (CFU/mL) to 0 CFU/mL. However, E. coli reduced the concentration from 5,000 CFU/mL to 0 CFU/mL, which led to a 100% elimination. Also, reduced protozoa, specifically Giardia, from a concentration of 1,000 colony-forming units per milliliter (CFU/mL) to a complete absence of colony-forming units (0 CFU/mL), resulting in a 100% reduction. The total eradication of these microbial pollutants verifies that the water treatment procedure is exceedingly efficient in guaranteeing the microbiological integrity of the water. The complete elimination of germs in the treated water indicates that it is safe for human consumption and use.

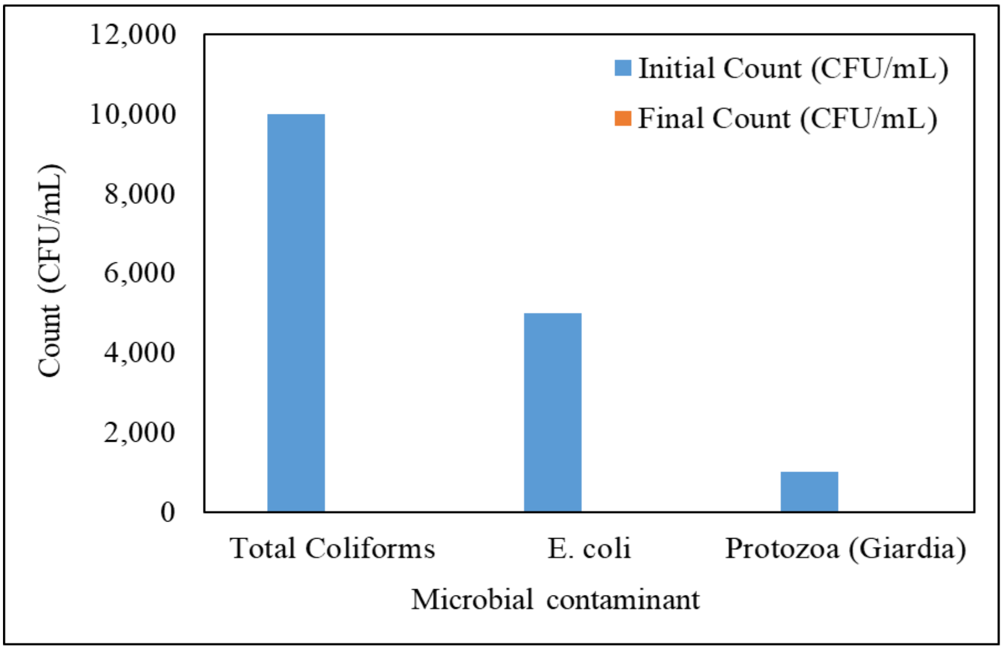

Figure 3. Count of microbial contaminants (CFU/mL).

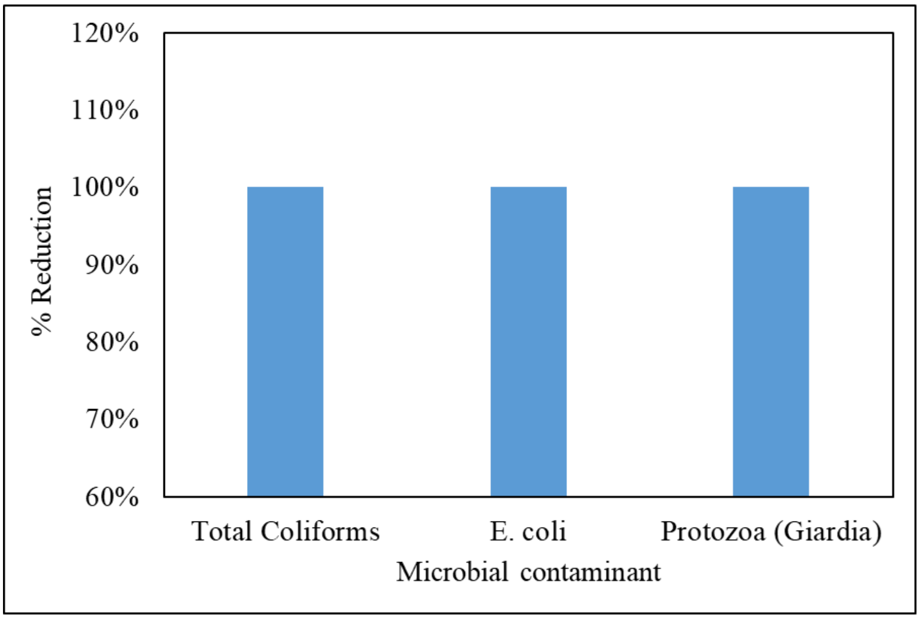

Figure 4. % reduction of microbial contaminants for different water samples.

3.4 Total Dissolved Solids Reduction

Source 3 provides data that demonstrates the effectiveness of the water treatment method in decreasing the amount of total dissolved solids (TDS) in groundwater.

The initial Total Dissolved Solids (TDS) measurement was 850 mg/L, suggesting a significant concentration of dissolved minerals and other solid substances in the water. This high TDS level has the potential to impact the flavour, safety, and overall quality of the water. After the treatment, the final total dissolved solids (TDS) concentration dropped to 15 mg/L, representing a 98.2% reduction (**Table 2**).

The substantial reduction demonstrates the treatment's efficacy in purifying the water by eliminating almost all dissolved solids. The TDS level of 15 mg/L indicates that the treated groundwater has significantly improved in quality, making it suitable for drinking and other uses. The treatment method effectively guarantees that the water complies with safety regulations, thereby improving both its safety and taste.

Table 2. TDS concentration and % reduction.

Water Source	Initial TDS (mg/L)	Final TDS (mg/L)	% Reduction
Source 3	850	15	98.20%

Table 2 demonstrates a substantial decrease in Total Dissolved Solids (TDS) levels, dropping from 850 mg/L to 15 mg/L after the filtration process. This decrease validates the effectiveness of the reverse osmosis membrane in purifying water by removing dissolved solids and desalinating it, thus meeting the drinking water requirements set by the World Health Organization (WHO, 2020).

3.5 Overall Performance

The integration of filtering stages demonstrated significant efficacy in enhancing the overall quality of water. The ultimate purified water from all origins satisfied or exceeded the World Health Organization (WHO) standards for drinking water in terms of clarity, chemical impurities, microbiological composition, and total dissolved solids (TDS). **Table 3** provides a summary of the system's performance across various water sources.

Table 3 data verifies that the filtered water from all sources complied with the drinking water requirements set by the World Health Organization (WHO). The incorporation of activated carbon, ceramic, and reverse osmosis filtration stages successfully tackled a diverse array of pollutants, ensuring that the water is suitable for drinking purposes.

Table 3. Summary of the system's performance across various water sources.

Water Source	Turbidity (NTU)	TDS (mg/L)	VOCs (mg/L)	Microbial Load (CFU/mL)	WHO Standards
Urban Tap Water (Source 1)	0.5	120	0.01	0	Yes
River Water (Source 2)	0.8	50	-	0	Yes
Source 3	0.4	15	-	0	Yes

4. DISCUSSION & FUTURE SCOPE

The study showcases the efficacy of the modern water filtration system, which provides a holistic approach to water purification by effectively eliminating a diverse range of pollutants from various water sources. The results show a big drop in turbidity, chemical pollutants, microbiological presence, and total dissolved solids (TDS). Each filtration phase contributed differently to the overall process of purification.

The activated carbon filter demonstrated exceptional efficacy in eliminating organic pollutants and enhancing the flavour and scent of the water. The ceramic filter, which is antibacterial, made sure that harmful microbes were gone, and the reverse osmosis membrane finished the job by getting rid of dissolved solids and heavy metals.

In general, the system's performance is consistent with the findings in previous studies on the efficacy of multi-stage filtering systems (Gupta et al., 2018; Singh & Dhillon, 2021). However, the research also emphasizes the importance of routine upkeep, particularly for the RO membrane, to guarantee constant performance in the long run.

Future research endeavors should prioritize the enhancement of the system's energy efficiency and investigate the feasibility of incorporating renewable energy sources to sustainably power the filtering process, thereby enabling its application in distant or off-grid regions.

5. CONCLUSIONS

This study showcased the efficacy of a state-of-the-art water filtration system in purifying various water sources, such as urban tap water, river water, and groundwater. The system, which has stages of activated carbon, ceramic, and reverse osmosis (RO) filtration, made the water quality much better by getting rid of physical, chemical, and biological impurities.

Key Findings:

The ceramic filter achieved a turbidity reduction of up to 99.5%, bringing the levels within the drinking water guidelines set by the World Health Organization (WHO).

The system achieved a removal rate of over 96% for volatile organic compounds (VOCs) and chlorine and a rate of more than 99% for heavy metals such as lead and arsenic, resulting in excellent water

purification.
The ceramic filter achieved complete eradication of hazardous bacteria, thereby guaranteeing water that is free from any microbiological risks.
The RO membrane achieved a 98.2% reduction in total dissolved solids (TDS), specifically in groundwater.
The study validates that the advanced water filtration system is a comprehensive remedy for generating potable water from diverse sources.
The modular design's customizable nature allows it to be used in a variety of environments, demonstrating its potential for wider application in urban, rural, and industrial settings. Potential future investigations could focus on augmenting the system's energy efficiency and sustainability.
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