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Development of a Multi-Layer Herbal Water Filter for Bacterial Removal - A Review

Madhuri Barmase[1], Prof. Rohit P. Deshmukh[2]
[1]Research Scholar, Civil Engineering Department, Swaminarayan Siddhanta Institute of Technology, Nagpur
[2]Assistant Professor, Civil Engineering Department, Swaminarayan Siddhanta Institute of Technology, Nagpur

Abstract: The increasing demand for clean and safe drinking water has driven research toward cost-effective and eco-friendly filtration methods. This review explores the development and effectiveness of a multi-layer herbal water filter designed for bacterial removal. Herbal filtration technology utilizes bioactive compounds from medicinal plants to enhance microbial removal efficiency while ensuring sustainability. The study investigates various herbal materials, their antibacterial properties, and their integration into a layered filtration system. Comparative analysis with conventional filtration methods highlights the advantages of herbal filtration, including affordability, biodegradability, and minimal environmental impact. This review aims to provide insight into the potential of herbal-based filtration as an alternative to chemical-based water purification techniques.
Keywords: Herbal water filter, bacterial removal, bioactive compounds, sustainable filtration, water purification.

I. INTRODUCTION

A. Introduction

Access to clean and safe drinking water is essential for public health and environmental sustainability. Traditional filtration techniques often involve chemical treatment, which may lead to secondary pollution or health concerns. Herbal filtration systems offer an alternative approach by utilizing naturally occurring bioactive compounds with antibacterial properties. This review discusses the development and application of multi-layer herbal water filters for effective bacterial removal.

The development of a multi-layer herbal water filter for bacterial removal has the potential to make a significant and lasting contribution to addressing global water quality challenges. This innovative solution directly tackles the issue of bacterial contamination in water, a leading cause of waterborne diseases such as cholera, typhoid, and dysentery, especially in rural and economically disadvantaged regions. By utilizing locally available and eco-friendly herbal materials such as neem, tulsi, and moringa, the project promotes sustainable and cost-effective water purification methods that are accessible to resource-constrained communities. The filter design emphasizes simplicity, low cost, and ease of maintenance, ensuring it can be widely adopted at both household and community levels. Beyond improving public health, the project supports environmental sustainability by relying on biodegradable materials, reducing dependency on energy-intensive and waste-generating conventional filtration systems. It also aligns with global and national goals, such as the United Nations' Sustainable Development Goal 6 (Clean Water and Sanitation) and India's Jal Jeevan Mission, fostering progress toward universal access to safe drinking water. Additionally, the project contributes to scientific knowledge by exploring the antimicrobial properties of herbal materials, paving the way for future innovations in natural and sustainable water treatment technologies. Its scalable design allows for adaptability across various settings, from individual households to large-scale community treatment systems, making it a versatile tool in the fight against water contamination. Ultimately, this project has the potential to improve health outcomes, enhance water security, and promote sustainable development, leaving a lasting impact on communities worldwide.

B. Components of Herbal Water Filtration System

A multi-layer herbal water filter consists of different filtering media integrated with herbal extracts known for their antibacterial properties. The key components include:

- Primary filtration layer: Removes large particulate matter and sediments.
- Activated charcoal layer: Adsorbs organic contaminants and improves water clarity.
- Herbal-infused layer: Contains medicinal plant extracts such as neem, tulsi, and moringa, which exhibit strong antibacterial properties.
- Sand and gravel layers: Enhance physical filtration and improve microbial retention.

C. *Mechanism of Bacterial Removal*

Herbal filtration mechanisms rely on multiple physical and biological interactions:

- Adsorption: Herbal compounds adhere to bacterial cell walls, disrupting their metabolism.
- Antimicrobial activity: Certain phytochemicals inhibit bacterial growth by altering cellular functions.
- Filtration efficiency: The combination of porous media and bioactive layers enhances microbial removal.

D. *Comparative Analysis with Conventional Filtration Techniques*

Table 1: Comparative Analysis with Conventional Filtration Techniques

Parameter	Herbal Water Filter	Conventional Filters
Cost-effectiveness	Low	Moderate to High
Environmental Impact	Minimal	May generate chemical waste
Antibacterial Efficiency	High (herbal bioactive compounds)	Varies (chlorination, UV, RO)
Maintenance	Low	High (filter replacement, chemical dosing)
Sustainability	High	Moderate

E. *Advantages and Challenges*

1) *Advantages*

- Eco-friendly and biodegradable filtration approach.
- Cost-effective alternative to conventional chemical-based filtration.
- No harmful by-products in treated water.
- Easy implementation in rural and resource-limited areas.

2) *Challenges*

- Standardization of herbal extract concentration and efficiency.
- Long-term stability and shelf life of herbal components.
- Need for further research on large-scale implementation.

II. LITERATURE REVIEW

A. *Overview*

Access to clean and safe drinking water is a fundamental human right, yet it remains an unmet necessity for millions of people worldwide, particularly in rural and low-income regions. The growing global water crisis, coupled with the rise of waterborne diseases, has prompted researchers, governments, and public health organizations to explore effective, affordable, and sustainable solutions for water purification. The literature surrounding water treatment technologies is vast, encompassing traditional approaches such as chlorination, ultraviolet (UV) disinfection, and membrane filtration, as well as newer innovations focusing on eco-friendly, low-cost alternatives like natural coagulants, biosorbents, and plant-based filtration systems. This chapter reviews key studies and findings relevant to the development of herbal water filters, focusing on bacterial contamination, herbal materials with known antimicrobial properties, and the design of multi-layer filtration systems. By synthesizing existing knowledge, this review establishes the foundation for the current research, identifies gaps in the literature, and highlights the need for further exploration of herbal-based filtration systems as a promising solution for community-scale water treatment in resource-constrained areas.

B. *Waterborne Diseases & Bacterial Contamination*

Waterborne diseases, primarily caused by bacterial pathogens, continue to pose a severe threat to public health, especially in developing countries where access to improved water sources is limited. According to the World Health Organization (WHO), contaminated water is responsible for over 485,000 deaths annually due to diarrheal diseases alone, with millions of additional cases linked to bacterial pathogens such as Escherichia coli, Vibrio cholerae, Salmonella spp., and Shigella spp. These bacteria enter water sources through human and animal waste, agricultural runoff, and improper sanitation practices, leading to widespread outbreaks of cholera, typhoid fever, and dysentery, particularly in rural and peri-urban areas. Studies have shown that even seemingly clear water can harbor significant microbial loads, underscoring the need for effective filtration systems that can reliably remove bacterial contaminants. Conventional disinfection techniques like chlorination, although effective, are associated with the formation of potentially harmful byproducts such as trihalomethanes (THMs) and haloacetic acids (HAAs), while advanced methods like UV irradiation and membrane filtration often require high operational costs, skilled maintenance, and continuous energy supply, making them less feasible for small-scale and decentralized applications. Therefore, the challenge of bacterial contamination in drinking water necessitates the exploration of sustainable, low-cost alternatives that can address microbial safety without introducing additional chemical risks or financial burdens. This study focuses on addressing this challenge by investigating the potential of herbal materials as natural antibacterial agents in water filtration systems.

João P S Cabral et. al. (2010). “Water Microbiology: Bacterial Pathogens and Water”, [1] Provides an in-depth analysis of the global challenge of ensuring safe drinking water and controlling bacterial waterborne diseases such as cholera, typhoid fever, and bacillary dysentery. It emphasizes that access to clean water remains a critical issue, with millions affected by waterborne infections annually. The article explores the biology, ecology, and transmission cycles of key bacterial pathogens, particularly Vibrio cholerae (cholera), Salmonella enterica serovar Typhi (typhoid fever), and Shigella spp. (dysentery). It also highlights the emerging importance of pathogenic Escherichia coli strains in waterborne diseases, underscoring the need to understand these pathogens' survival and proliferation in environmental waters. The review further discusses the concept of fecal indicator bacteria (FIB) in microbiological water quality monitoring, focusing on the roles of E. coli and enterococci as key markers, while acknowledging their limitations, such as variability in survival rates and sources. Sources of fecal contamination, including human sewage, animal waste, and agricultural runoff, are identified as major contributors to bacterial pollution in water bodies. The article advocates for routine microbiological analysis of drinking water, recommending the use of culture-based methods for E. coli detection as a baseline, with enterococci quantification as a complementary test where feasible. Additionally, the review calls for further research into the reliability of ammonia as a preliminary indicator for emergency fecal pollution events. Overall, the paper stresses that ensuring universal access to safe drinking water is a major challenge of the 21st century, and it highlights the urgent need for strengthened microbiological monitoring programs, robust infrastructure, and better understanding of fecal bacteria dynamics in water ecosystems to safeguard public health.

Flor Yazmín Ramírez-Castillo et. al. (2015), “Waterborne Pathogens: Detection Methods and Challenges”, [2] discusses the global public health concern posed by waterborne pathogens, which are responsible for significant morbidity, mortality, and economic burdens due to the need for extensive prevention and treatment strategies. Waterborne diseases are closely linked to environmental pollution and degradation, highlighting the need for robust water quality management. Despite ongoing efforts to maintain water safety, waterborne outbreaks continue to occur worldwide. The article emphasizes the critical role of accurate pathogen detection and water quality monitoring in guiding water distribution infrastructure design, selecting appropriate treatment technologies, and implementing effective outbreak prevention strategies. Advanced diagnostic tools, including sensitive and reproducible molecular techniques, have been developed to detect a wide range of pathogens in water, including those that are viable but non-culturable (VBNC) and those embedded in biofilms, which traditional culture methods often miss. The review also introduces the Quantitative Microbial Risk Assessment (QMRA) framework as a valuable tool for evaluating potential risks of pathogen contamination. QMRA facilitates informed decision-making by integrating data on pathogen occurrence, detection methods, and environmental conditions. The article provides an overview of recent waterborne outbreaks, highlighting the importance of continuous surveillance, improved detection techniques, and QMRA for ensuring public health protection. By integrating molecular diagnostics with risk assessment, this review underscores the need for comprehensive strategies in monitoring, detecting, and mitigating waterborne pathogens to prevent future outbreaks.

Sardar Khan et. al. (2020), “Bacterial contamination in drinking water of urban Peshawar: a comparative study at the sources and user points of tube wells”, [3] Investigated the microbiological quality of drinking water in urban areas of Peshawar District, Khyber Pakhtunkhwa, Pakistan. The research focused on assessing water samples collected from both the tube well sources and the user points, analyzing them for physicochemical parameters such as pH, turbidity, electrical conductivity (EC), and total dissolved solids (TDS), along with the presence of bacterial contaminants. While the physicochemical characteristics were found to be within the safe limits prescribed by the World Health Organization (WHO) guidelines for drinking water, the study revealed alarming levels of bacterial contamination in the water. The results showed that the drinking water samples were heavily contaminated with fecal coliforms, Escherichia coli (E. coli), and other pathogenic bacteria, including Salmonella spp., Shigella spp., Vibrio cholerae, Staphylococcus aureus, and Pseudomonas aeruginosa. These bacterial pathogens are associated with severe gastrointestinal infections and waterborne diseases, posing a significant public health risk to the local population. The study highlights the urgent need for interventions such as chlorination or boiling of drinking water before use, to prevent the spread of diseases and protect the health of the community.

The findings emphasize that even when basic physicochemical parameters meet regulatory standards, the presence of bacterial pathogens can undermine water safety, underscoring the critical need for regular microbial monitoring and effective disinfection practices to ensure the provision of safe drinking water.

Godfrey Michael Shayo et. al. (2023), “Severity of waterborne diseases in developing countries and the effectiveness of ceramic filters for improving water quality”, [4] Examines the global challenges of waterborne diseases, particularly in developing countries, where access to safe drinking water is limited and water-related diseases remain a major public health concern. The study highlights that by 2025, an estimated 3 billion people will face water stress, exacerbating issues of waterborne diseases and fatalities in both industrialized and developing nations. The review evaluates various strategies for water treatment and disease prevention, including traditional methods such as boiling, chlorination, flocculation, solar disinfection, and modern approaches like ceramic-based filtration systems. These techniques are assessed for their ability to remove contaminants like bacteria, viruses, and chemicals, and their effectiveness depends on the specific pollutants present in the water. The authors emphasize that the proper application of these strategies is critical to ensuring safe drinking water. The article also points out that in developing countries, a combination of these methods has contributed to a significant reduction in the prevalence of waterborne diseases, ranging from 50% to 90%. Notably, the study underscores the growing adoption of ceramic-based filtration systems, as they are affordable, highly effective in removing pathogens, easy to maintain, and can be produced locally. This makes them a promising solution for improving water quality and preventing waterborne diseases in resource-limited settings.

Nazish Mazhar Ali et. al. (2025), “Impact of Water Pollution on Waterborne Infections: Emphasizing Microbial Contamination and Associated Health Hazards in Humans”, [5] Explores the severe public health risks posed by water pollution, focusing on microbial contaminants and the diseases they cause. The study highlights that water pollution arises from multiple sources, including industrial waste, agricultural runoff, untreated sewage, and urban activities, all of which introduce harmful microorganisms into water bodies. Environmental factors like rainfall, climate variability, and soil characteristics also contribute to the spread and persistence of these contaminants, particularly in developing countries where inadequate sanitation and water management exacerbate the problem. Millions of people worldwide, especially in underdeveloped regions, suffer annually from waterborne infections such as gastrointestinal diseases caused by bacterial pathogens like Escherichia coli, Vibrio cholerae, Salmonella spp., as well as viruses and protozoans like Giardia lamblia and Cryptosporidium parvum. The review also discusses less commonly addressed pathogens such as Legionella spp., Pseudomonas aeruginosa, and Campylobacter jejuni, which cause significant illnesses. Despite improvements in water treatment and sanitation in some regions, outbreaks continue to occur in areas with poor infrastructure and limited resources. The authors stress the urgent need for better water management strategies, stricter pollution control regulations, and the development of advanced, cost-effective treatment technologies to mitigate waterborne diseases. Protecting public health requires a multidisciplinary approach that includes enhanced monitoring, stricter policy enforcement, and innovative solutions to ensure safe water, especially in regions vulnerable to water scarcity and microbial contamination.

C. Herbal Materials For Water Treatment

The use of herbal materials for water treatment has gained significant interest in recent years due to their natural abundance, eco-friendly properties, and potent antimicrobial activities. Various plant-based materials, including neem (Azadirachta indica), tulsi (Ocimum sanctum), moringa (Moringa oleifera), guava leaves (Psidium guajava), and turmeric (Curcuma longa), have been studied for their ability to inhibit bacterial growth in water. Neem is known for its broad-spectrum antimicrobial activity, primarily due to compounds like nimbin, nimbidin, and azadirachtin, which disrupt bacterial cell walls and metabolic processes. Tulsi, often revered in traditional medicine, contains bioactive compounds such as eugenol, ursolic acid, and carvacrol, which exhibit strong antibacterial, antifungal, and antioxidant properties. Moringa seeds, beyond their nutritional benefits, have been shown to contain cationic proteins that act as natural coagulants, aiding in the flocculation of suspended particles and contributing to bacterial cell aggregation and sedimentation. Studies such as those by Lea (2010) and Pritchard et al. (2010) have demonstrated the effectiveness of moringa seed extracts in reducing bacterial counts in water samples. Similarly, turmeric contains curcumin, a compound with proven antibacterial and anti-inflammatory properties, while guava leaves are rich in flavonoids and tannins that inhibit bacterial enzyme activity. The use of these herbal materials not only offers a natural and cost-effective alternative to chemical disinfectants but also aligns with the principles of sustainability and community-level water management. However, despite their potential, most studies have focused on the antibacterial efficacy of single plant extracts in laboratory conditions, with limited research exploring the synergistic effects of combining multiple herbal materials in a filtration system. This research aims to build upon these findings by integrating neem, tulsi, and moringa in a multi-layer filter to enhance bacterial removal performance and water quality improvement.

Sowmeyan et al. (2011) conducted a comprehensive study titled "Effectiveness of herbs in community water treatment", [1] They explored the potential use of various herbal plants for water purification aimed at rural communities. The study evaluated seven herbal materials, including Neem, Moringa Oleifera, Vetiver, Nirmali, Luffa cylindrica, and orange peel, for their effectiveness in removing key water contaminants such as turbidity, total hardness, total dissolved solids (TDS), fluoride, chloride, calcium, and magnesium. The research findings demonstrated that these herbal agents could significantly reduce these contaminants to levels that meet the World Health Organization (WHO) drinking water standards. This study not only confirmed the feasibility of using natural, low-cost herbal solutions for water treatment but also emphasized their practical application by developing an affordable water treatment kit, making it highly relevant for improving water quality in rural areas with limited access to conventional treatment technologies. The successful reduction of multiple parameters highlights the potential for these herbs to be integrated into sustainable water treatment practices that are environmentally friendly and economically viable.

Yevate and Mane (2017) “Low-Cost Water Purifier by Using Natural Herbs”, [2] Specifically tulsi (Ocimum tenuiflorum) and neem (Azadirachta indica), aimed at rural and remote communities. Their research addresses the challenge of fluoride contamination in groundwater, which is a significant health concern in many parts of India, leading to dental and skeletal fluorosis. The authors highlight that while several defluoridation technologies exist—such as chemical separation, reverse osmosis, and nano-filtration—these are often expensive, energy-intensive, and require skilled operators, making them unsuitable for impoverished rural areas. The proposed system combines natural substances with clay and calcium hydroxide [$Ca(OH)_2$] in a filter to remove fluoride effectively while being cost-effective, portable, and energy-efficient. Experimental analysis of well and bore well water samples demonstrated the system's potential to provide safe drinking water with reduced fluoride content, addressing a critical need for affordable and user-friendly purification methods in economically disadvantaged regions.

Vijayalakshmi et. al. (2018), “Treatment of Water by Traditional Methods”, [3] explored the relevance and effectiveness of traditional water treatment methods that have been used for generations. Despite the availability of modern water purification technologies such as reverse osmosis and household filtering devices, these advanced systems often result in demineralized water, which lacks essential minerals like calcium, magnesium, fluoride, and iron that are vital for human health. The authors emphasize that traditional methods, although developed without modern scientific validation, continue to offer significant benefits in improving water quality by naturally retaining or enhancing mineral content. Their research particularly highlights the use of natural materials such as Vetiver grass (used to improve mineral content) and Amla (Indian gooseberry), which are known to contribute positively to the chemical composition of treated water. These methods not only improve water quality but also provide health benefits associated with the minerals present, which modern filtration systems often remove. The study underlines the need to revisit and integrate such traditional techniques with modern water treatment approaches to provide safe, mineral-rich drinking water, especially in rural and resource-limited settings. By validating the efficiency and practical applicability of these ancestral practices, the authors propose a sustainable, cost-effective, and culturally acceptable alternative to expensive and energy-intensive water treatment technologies.

Katubi et al. (2021), “Aloe vera as Promising Material for Water Treatment: A Review”, [4] highlights Aloe vera as a highly promising and sustainable natural material for water treatment applications due to its unique chemical composition and environmentally friendly nature. Aloe vera has been widely investigated as an effective coagulant, flocculant, and biosorbent capable of removing a broad spectrum of pollutants from water, including suspended solids, turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD), heavy metals, dyes, and organic contaminants such as phenols. The review presents evidence from various studies demonstrating that Aloe vera-based materials, prepared using different extraction and processing techniques, achieve significant pollutant removal efficiencies in laboratory-scale water treatment experiments. Notably, Aloe vera’s enzymatic components, such as carboxypeptidase, glutathione peroxidase, and superoxide dismutase, have been shown to actively degrade complex textile dyes, further enhancing its applicability in wastewater remediation. The review underscores that Aloe vera not only improves solid-liquid separation during sludge treatment but also offers adsorption capacities comparable to other biosorbents derived from natural sources. Given Aloe vera’s abundance, biodegradability, low cost, and eco-friendly profile, it holds considerable potential as an alternative to conventional chemical treatments in water purification, particularly in resource-limited settings. However, the authors note that removal efficiencies depend strongly on the specific preparation methods and characteristics of the wastewater treated, suggesting that optimization and standardization are key for its practical application.

Jouyandeh et al. (2022) ‘Green products from herbal medicine wastes by subcritical water treatment”, [5] Recognizing the environmental challenges posed by the disposal of HMWs, especially amid increased concerns during the COVID-19 pandemic, the authors explored a green conversion process to transform these wastes into valuable products. The study employed batch-wise subcritical water extraction at varying temperatures (127–327 °C), pressures (0.792–30.0 MPa), and times (1–60 min) in a stainless-steel reactor.

Remarkably, the process achieved up to 99% conversion of waste to clean products within 5 minutes at high temperatures (>277 °C). The extraction yielded significant amounts of organic acids (glycolic, formic, lactic, acetic acids), amino acids (aspartic acid, threonine, glycine), and sugars (glucose, fructose, cellobiose). Additionally, acetone-soluble extracts (fat phase) reached a maximum yield of 21% at around 357 °C. This research demonstrates a sustainable and efficient method to recover valuable bioactive compounds from herbal waste, reducing environmental pollution and supporting circular economy practices in pharmaceutical waste management.

Bindhu et al. (2023) investigated the "Water Purification Potential of Selected Medicinal Plants", [6] They examined the physical, chemical, and bacteriological effects of four medicinal plants—Coriandrum sativum (Coriander), Moringa oleifera, Azadirachta indica (Neem), and Ocimum tenuiflorum (Tulsi)—on polluted water treatment. The study found that the addition of these plants generally increased turbidity; however, when evaluating chemical properties such as pH, chemical oxygen demand (COD), biological oxygen demand (BOD), and bacteriological parameters like coliform counts, Neem demonstrated superior efficacy in purifying polluted water. Tulsi was identified as the second-best plant for water purification, while Coriander and Moringa also showed promising results toward improving water quality to potable standards. The research emphasizes the potential use of these medicinal plants, especially Neem, as sustainable and accessible options for water treatment in regions lacking adequate potable water supplies. This study contributes valuable insights for developing eco-friendly and affordable purification techniques utilizing natural plant resources.

Konkobo et al. (2023), "Evaluation of the effectiveness of some local plant extracts in improving the quality of unsafe water consumed in developing countries", [7] Explored the potential of various local plant extracts as natural biocoagulants to replace aluminum sulfate in water treatment. The study assessed nine different plant extracts for their coagulation and flocculation capabilities in reducing turbidity in surface water samples. Among these, seeds of Moringa oleifera and Boscia senegalensis exhibited outstanding coagulant activities with turbidity reductions of 84.83% and 82.97%, respectively, after 1 hour of decantation. Optimized treatment with Moringa oleifera at 1 g/L resulted in a 98% turbidity abatement, producing water of 4.6 NTU after 2 hours. Similarly, Boscia senegalensis treatment achieved comparable results with 2.5 g/L concentration. The study further demonstrated that combining these biocoagulants with mucilages from Opuntia ficus indica and Aloe vera significantly reduced decantation time to just 15 minutes while maintaining high pathogen removal efficiency (~99%). These findings suggest that these plant-based coagulants serve as effective, low-cost, and sustainable alternatives to chemical coagulants, especially for improving access to potable water in low- and middle-income regions.

Zhillika Pruthi et. al. (2023), "Effect of Ayurveda water purification method on total dissolved solutes in water", [8] Explores the traditional Ayurvedic techniques of water purification and their impact on the quality of drinking water, specifically focusing on the Total Dissolved Solids (TDS) parameter. Water is a fundamental necessity for life, and maintaining its purity is critical as it is involved in numerous bodily functions. Ancient Ayurvedic texts, particularly those of Acharya Sushruta, have described several natural water purification methods that involve storing water in different types of vessels such as silver, copper, and clay, as well as using herbs like Kataka Beeja (Strychnos potatorum Linn.). These traditional approaches are rooted in ancient wisdom and aim to enhance water quality by naturally removing impurities. The study highlights that TDS—comprising inorganic salts such as bicarbonates, sulfates, and chlorides, alongside organic matter—serves as a crucial parameter for assessing the fitness of water for human consumption. Elevated TDS levels can make water unfit for consumption, potentially causing health issues such as nausea, vomiting, and dizziness. The research emphasizes that, with modern urbanization and changes in lifestyle and dietary patterns, there is a pressing need to revisit and evaluate these simple yet effective traditional purification methods. By examining the impact of Ayurveda-based water storage techniques on TDS levels, the study underscores the potential of these practices in improving water quality in an accessible, eco-friendly, and sustainable manner, thereby contributing to the preservation of public health.

Jatin Kumar et. al. (2024), "Recent advancements in utilizing plant-based approaches for water and wastewater treatment technologies", [9] Highlights the critical need for sustainable methods in water purification to address the growing global water crisis. Factors such as overpopulation, rapid industrialization, urbanization, and the expansion of agricultural practices have severely impacted both the availability and quality of water resources. With projections indicating that nearly 4 billion people may lack access to clean water by 2025, it becomes essential to adopt effective water treatment technologies. Traditional water and wastewater treatment methods primarily rely on chemical and physical processes, such as coagulation, disinfection, filtration, and adsorption, often using substances like alum, lime, chlorine, bromine, activated alumina, silica gel, and zeolites. While these chemicals are effective, their high costs, environmental concerns, and potential adverse health effects highlight the need for greener alternatives.

In this context, plant-based materials—including coagulants, adsorbents, and disinfectants—have emerged as promising, eco-friendly substitutes for conventional chemicals. The review provides a comprehensive analysis of the mechanisms, benefits, and limitations of using plant-derived materials for water treatment, filling a gap in existing literature by offering an integrated perspective that combines all three approaches—coagulation, adsorption, and disinfection. By exploring how plant-based materials can enhance water treatment efficiency while minimizing ecological harm, the study contributes to the development of more sustainable and cost-effective water purification methods. This work is particularly valuable for researchers focusing on green water technologies, offering insights into how natural materials can play a significant role in ensuring access to safe and clean water in the face of global challenges.

Bahati Shabani Nzeyimana et. al. (2024) "Sustainable sewage water treatment based on natural plant coagulant: Moringa oleifera", [10] Explores the potential of Moringa oleifera, a plant native to the Indian subcontinent, as a sustainable and eco-friendly solution for treating sewage water. In the context of global water scarcity and environmental challenges, the study focuses on employing Moringa oleifera as a natural plant coagulant (NPC) to improve water quality without relying on synthetic chemicals. Using a standard jar test method, the study evaluates the coagulation and flocculation capacity of Moringa oleifera in reducing turbidity and impurities in sewage water. Experimental results demonstrated that an optimum dose of 0.4 g/1000 mL achieved impressive reductions in key water quality parameters: turbidity by 92%, chemical oxygen demand (COD) by 88%, total solids by 96%, chloride by 75%, total hardness by 74%, and inorganic phosphorous by 68%. However, the study did not report specific results for biological oxygen demand (BOD), highlighting an area for future investigation. The findings indicate that Moringa oleifera is not only effective in improving water quality but also holds promise for advancing sustainable, low-cost wastewater treatment methods that contribute to environmental protection and public health. The study concludes by emphasizing the need for further research to explore the scalability of this green technology and its applicability to different wastewater types, paving the way for more widespread adoption of plant-based coagulants in water and wastewater treatment systems.

D. Multi-Layer Filtration Systems

Multi-layer filtration systems are designed to mimic natural filtration processes by combining various filter media to target different contaminants in water, such as suspended solids, turbidity, organic matter, and pathogens. Typically, these systems use a sequence of layers, including coarse gravel for large particle removal, sand for finer particles, activated carbon for adsorption of organic pollutants, and sometimes bio-layers or slow sand filters to support biological activity. The integration of herbal materials into multi-layer filters introduces an additional mechanism for microbial inactivation, combining physical filtration with natural antimicrobial action. Several studies have demonstrated the benefits of multi-layer filters in improving water quality, particularly in rural and low-resource settings. For instance, a study by Mwabi et al. (2011) on household water treatment systems in South Africa reported significant reductions in turbidity and bacterial counts using multi-barrier approaches. Research by Pritchard et al. (2009) highlighted the potential of incorporating moringa seed powder into sand filters to enhance bacterial removal efficiency. However, the design of multi-layer systems often requires careful consideration of media selection, layer thickness, flow rate, and maintenance requirements to optimize performance and longevity. While multi-layer filtration is a well-established concept, there remains a lack of standardization in incorporating herbal materials into these systems. Moreover, most studies have evaluated multi-layer filters over short testing periods, with limited data on long-term bacterial removal efficacy, filter clogging, and maintenance needs. The present research seeks to address these gaps by developing and testing a multi-layer herbal filter that combines the physical filtration capacity of gravel and sand with the antibacterial properties of neem, tulsi, and moringa, aiming to provide a scalable, low-cost solution for safe drinking water.

E. Gaps In Existing Research

Despite promising findings in the fields of herbal water treatment and multi-layer filtration, significant gaps in existing research limit the practical implementation of such technologies for widespread community use. Firstly, many studies have been confined to small-scale laboratory setups, often using synthetic water samples or controlled bacterial cultures, which may not accurately represent the complex water quality conditions encountered in real-world scenarios, such as variable turbidity, organic load, and mixed bacterial populations. Secondly, while the antibacterial efficacy of individual herbal materials like neem, tulsi, or moringa has been demonstrated, there is limited research on their combined effects in a single filter system—potentially overlooking synergistic interactions that could enhance performance. Thirdly, the impact of herbal filtration on other water quality parameters, including pH, turbidity, total dissolved solids (TDS), and chemical oxygen demand (COD), has not been extensively studied, leaving questions about potential side effects or trade-offs.

Moreover, long-term studies assessing the durability, reusability, and consistency of herbal filters over multiple filtration cycles are scarce, raising concerns about filter lifespan and maintenance requirements. There is also a lack of standardized protocols for filter design, including layer arrangement, dosage of herbal materials, and flow rate optimization, which hinders reproducibility and scalability of the technology. Finally, community-level studies evaluating user acceptability, cultural perceptions, and the socio-economic feasibility of adopting herbal water filters remain limited, despite their importance for successful implementation. This research aims to bridge these gaps by developing a multi-layer herbal water filter using a combination of neem, tulsi, and moringa, conducting detailed water quality and bacterial analyses, and exploring the potential of the filter as a practical, low-cost solution for rural drinking water treatment.

III. PROPOSED METHODOLOGY

The proposed methodology framework for developing a multi-layer herbal water filter involves the following key stages:

1) Selection of Herbal Materials
   - Identification of herbs with strong antimicrobial properties such as Moringa oleifera, Neem (Azadirachta Indica), Tulsi (Ocimum Sanctum), and Turmeric (Curcuma Longa).
   - Evaluation of their effectiveness in bacterial removal through literature review and preliminary testing.
2) Filter Design and Layer Composition
   - Structuring a multi-layer filtration system with specific herbal materials for coagulation, adsorption, and bacterial inactivation.
   - Incorporating activated charcoal from herbal sources to enhance adsorption and purification.
3) Preparation of Filter Components
   - Drying and pulverizing herbal materials to obtain a fine powder for filtration.
   - Fabrication of filter cartridges with appropriate layering techniques to maximize water purification efficiency.
4) Experimental Setup and Water Sampling
   - Collecting contaminated water samples from different sources.
   - Constructing prototype filters and passing water through them under controlled conditions.
5) Microbiological and Physicochemical Analysis
   - Testing bacterial load reduction using standard microbial analysis methods.
   - Measuring physicochemical parameters such as turbidity, pH, and dissolved solids before and after filtration.
6) Performance Evaluation and Optimization
   - Comparing results with conventional filtration methods.
   - Optimizing the filter design based on experimental outcomes.

A. *Herbal Materials Used in Water Filtration*

Various herbs exhibit antimicrobial properties that can effectively reduce bacterial loads in contaminated water. Some commonly used herbal materials include:

1) Moringa Oleifera
   - Contains bioactive compounds such as isothiocyanates that possess antimicrobial properties.
   - Functions as a natural coagulant, reducing turbidity and bacterial count.
2) Neem (Azadirachta Indica)
   - Exhibits strong antibacterial properties due to the presence of nimbidin and azadirachtin.
   - Effective in eliminating Escherichia coli and other pathogenic bacteria.
3) Tulsi (Ocimum Sanctum)
   - Contains eugenol and other phytochemicals with potent antibacterial and antiviral properties.
   - Enhances the effectiveness of water filtration by preventing bacterial regrowth.
4) Turmeric (Curcuma Longa)
   - Curcumin acts as an antibacterial and anti-inflammatory agent.
   - Useful in combination with other herbal materials for enhanced filtration efficiency.
5) Activated Charcoal Derived from Herbal Sources
   - Absorbs contaminants and microorganisms.
   - Enhances overall filtration efficiency when used as a final layer in multi-layer filtration systems.

IV. CONCLUSION

The development of a multi-layer herbal water filter presents a promising approach to bacterial removal, providing a sustainable and cost-effective solution for water purification. Herbal extracts with antibacterial properties enhance microbial removal while reducing reliance on chemical-based treatments. Future research should focus on optimizing filter design, assessing long-term performance, and scaling up implementation to meet global water treatment needs.

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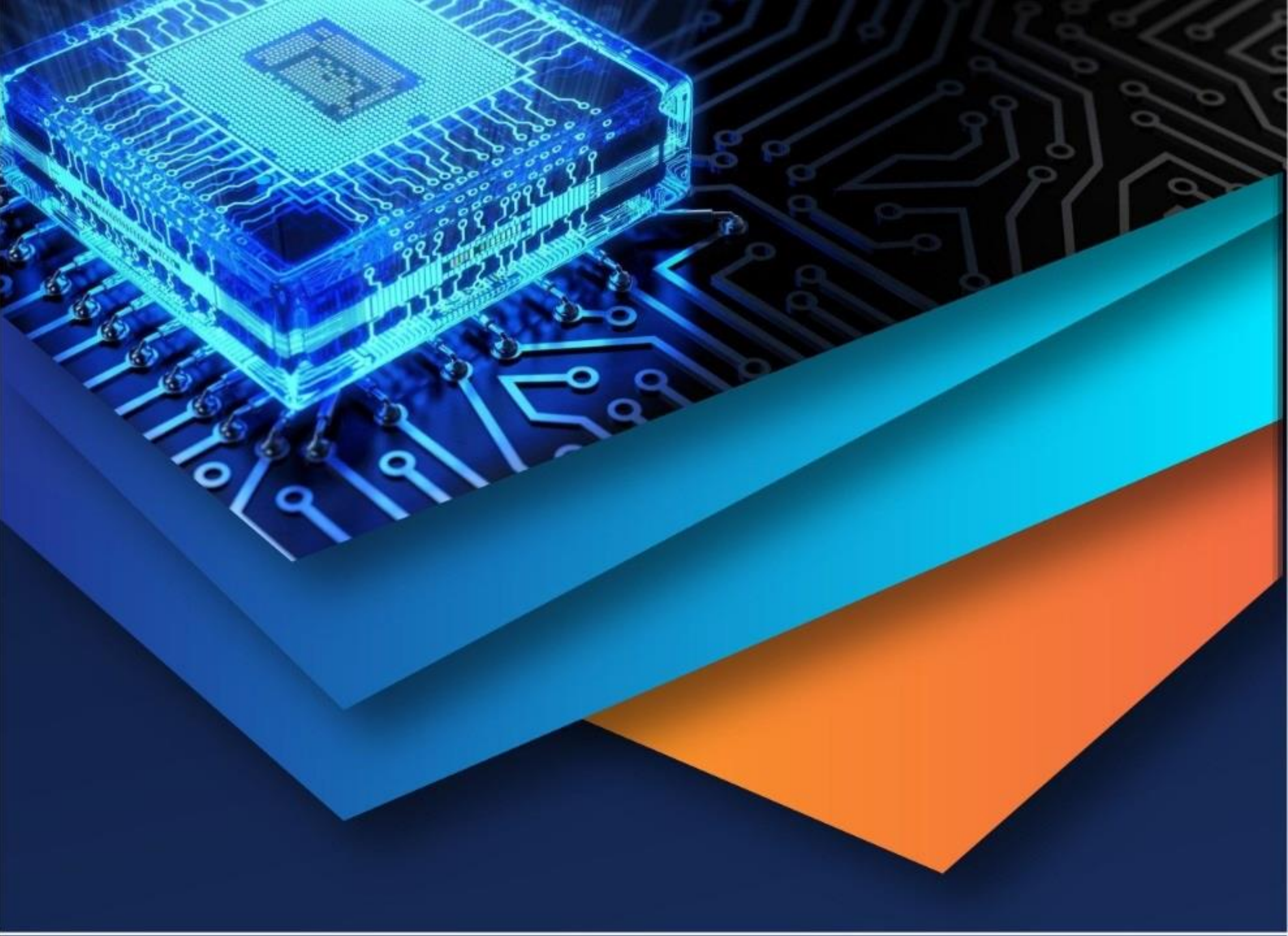

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