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Coir Fiber as a Sustainable Alternative to Polypropylene Water Filters: A Comparative Review

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Abstract: Access to safe drinking water remains a major global challenge due to increasing contamination from industrialization, agricultural activities, and urbanization. Conventional water filtration systems commonly utilize polypropylene (PP) filter cartridges owing to their low cost and ease of manufacturing. However, the non-biodegradable nature of polypropylene contributes significantly to environmental pollution and plastic waste generation. Consequently, there is growing interest in the development of sustainable and eco-friendly filtration materials derived from natural resources. Among various natural fibers, coir fiber has emerged as a promising candidate due to its abundance, biodegradability, low cost, high lignin content, and excellent durability in aqueous environments. This review critically evaluates the potential of coir fiber as an alternative filtration medium for water purification applications. The physical, chemical, and mechanical properties of coir fibers are discussed and compared with conventional polypropylene filtration materials. Various fiber modification techniques, filtration mechanisms, environmental impacts, and sustainability considerations are reviewed. Existing research gaps and future directions for the development of coir-based filtration composites are also highlighted.

Furthermore, the adoption of coir fiber-based filtration systems aligns with the objectives of the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land), by promoting sustainable water treatment technologies, reducing plastic waste, supporting circular bioeconomy practices, and minimizing environmental impacts associated with conventional filtration materials.

Keywords: Coir fiber, Water filtration, Sustainable materials, Polypropylene filter, Natural fiber composites, Water purification

I. INTRODUCTION

Water is an essential resource for human survival and socioeconomic development. Despite technological advancements, access to clean and safe drinking water remains a significant challenge in many parts of the world. According to international reports, millions of people continue to rely on contaminated water sources, exposing them to severe health risks.

Conventional water filtration systems extensively employ synthetic polymer-based materials such as polypropylene filters. These filters effectively remove suspended particles and sediments; however, their disposal contributes to environmental degradation due to their non-biodegradable nature. The accumulation of plastic waste has become a major global concern, prompting researchers to investigate sustainable alternatives.

Natural fibers have attracted considerable attention because of their renewable nature, biodegradability, and lower environmental footprint. Among these fibers, coir fiber derived from coconut husks represents a highly promising material for filtration applications. Coir fibers are widely available in tropical countries, possess excellent resistance to microbial attack, and exhibit remarkable durability under wet conditions.

This review aims to evaluate the suitability of coir fiber as an environmentally friendly alternative to conventional polypropylene filtration media.

II. CONVENTIONAL WATER FILTRATION MATERIALS

Conventional water filtration technologies play a crucial role in ensuring access to safe and potable water by removing suspended solids, microorganisms, dissolved contaminants and other pollutants. Over the past several decades, numerous filtration systems have been developed to address the growing challenges associated with water pollution and freshwater scarcity. Among these technologies, activated carbon filtration, membrane filtration, sediment filtration and reverse osmosis have emerged as the most widely adopted approaches in domestic, industrial and municipal water treatment applications. These technologies offer varying degrees of effectiveness depending on the nature and concentration of contaminants present in the water source.

Although conventional filtration systems have demonstrated high removal efficiencies, many rely heavily on synthetic materials that raise concerns regarding environmental sustainability and end-of-life disposal. Consequently, researchers are increasingly exploring environmentally friendly alternatives capable of delivering comparable filtration performance while reducing ecological impacts.

A. Polypropylene-Based Filtration Materials

Polypropylene (PP) is one of the most commonly used materials in water filtration systems due to its favorable mechanical properties, chemical resistance and low manufacturing cost. Polypropylene filter cartridges are extensively employed in household water purification units, industrial treatment plants and pre-filtration systems to remove suspended particles, sediments and turbidity-causing contaminants. The widespread use of polypropylene is largely attributed to its durability, lightweight nature and compatibility with various filtration configurations. Despite these advantages, polypropylene is a petroleum-derived synthetic polymer that is non-biodegradable and contributes significantly to plastic waste generation. The disposal of spent filter cartridges poses environmental challenges, particularly in regions lacking efficient waste management systems. As concerns regarding plastic pollution continue to grow globally, the long-term sustainability of polypropylene-based filtration systems has become a subject of increasing scrutiny among researchers and environmental policymakers.

Table 1

Polypropylene vs Coir Fiber Filter — Comparative overview

Parameter	Polypropylene filter	Coir fiber filter
Source	Petroleum-based	Natural biomass
Biodegradability	No	Yes
Filtration efficiency	High	Moderate to High *
Weight	Lightweight	Lightweight
Manufacturing cost	Low	Low
Chemical resistance	Excellent	Good
Environmental impact	High	Low
Sustainability	Limited	High
Disposal	Plastic waste	Biodegradable
Availability	Industrial production	Agricultural by-product

The increasing concern regarding environmental sustainability has motivated the search for biodegradable filtration materials.

B. Activated Carbon Filtration

Activated carbon filtration represents one of the most effective and widely utilized methods for removing organic pollutants, unpleasant odors, chlorine and various dissolved contaminants from water. The high surface area and porous structure of activated carbon provide numerous adsorption sites capable of capturing contaminants through physical and chemical interactions. Activated carbon filters are frequently incorporated into household water treatment systems, industrial purification processes and wastewater treatment facilities. Although activated carbon exhibits excellent adsorption performance, its production may involve energy-intensive processes and periodic replacement is required to maintain filtration efficiency. Furthermore, activated carbon alone may not effectively remove all microbial contaminants or dissolved salts, necessitating its integration with additional treatment technologies.

C. Membrane Filtration Technologies

Membrane-based filtration technologies have revolutionized modern water treatment by enabling highly efficient separation of contaminants based on particle size and molecular characteristics. These technologies include microfiltration, ultrafiltration, nanofiltration and reverse osmosis, each designed to target specific categories of contaminants. Microfiltration is primarily used for removing suspended particles and bacteria, whereas ultrafiltration offers enhanced removal of viruses and macromolecules. Nanofiltration and reverse osmosis are capable of eliminating dissolved salts, heavy metals and a broad range of organic pollutants. Despite their effectiveness, membrane systems often require substantial energy inputs, regular maintenance and significant capital investment. Membrane fouling remains one of the major operational challenges affecting system performance and longevity. Consequently, ongoing research focuses on developing sustainable membrane materials and hybrid filtration systems capable of improving efficiency while minimizing environmental impacts.

III. COIR FIBER AS A SUSTAINABLE MATERIAL FOR WATER FILTRATION

The increasing emphasis on sustainability has encouraged researchers to investigate natural fibers as environmentally friendly alternatives to conventional synthetic filtration materials.

Among the various plant-derived fibers available, coir fiber has attracted significant attention due to its abundance, biodegradability and favorable physical properties. Coir fiber is obtained from the outer husk of coconuts and is considered an agricultural by-product that is often underutilized despite its considerable potential for value-added applications. Unlike many synthetic materials, coir fibers originate from renewable resources and can naturally degrade at the end of their service life,

Figure 1 thereby reducing environmental burdens associated with waste disposal. The utilization of coir fibers in water filtration systems not only supports sustainable material development but also contributes to waste valorization and circular economy initiatives.

A. Physical and Chemical Characteristics of Coir Fiber

Coir fiber possesses a unique combination of physical and chemical properties that make it particularly suitable for filtration applications.

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One of its distinguishing characteristics is its high lignin content, which typically ranges between 40 and 45 percent and contributes to exceptional durability and resistance to microbial degradation. The fiber also contains cellulose and hemicellulose, which provide structural integrity and facilitate interactions with contaminants during filtration processes. The naturally rough surface morphology and porous structure of coir fibers enhance their ability to trap suspended particles and support adsorption mechanisms. Additionally, coir fibers exhibit excellent moisture resistance and maintain their structural stability under prolonged exposure to water, making them attractive candidates for sustainable filtration systems.Coir fiber is extracted from the husk of coconut fruits. It is considered an agricultural by-product and is abundantly available in countries such as India, Sri Lanka, Indonesia, and the Philippines.

Coir fibers possess several unique characteristics that make them highly suitable for water filtration and environmental applications. One of their most significant properties is their high toughness, which enables the fibers to withstand mechanical stresses and maintain structural integrity during prolonged use. Coir fibers also exhibit low density, making them lightweight and easy to process into filtration media and composite materials. In addition, their naturally porous structure provides good porosity, which facilitates water flow while enhancing the retention of suspended particles and contaminants. Another important advantage is their high moisture resistance, attributed to their elevated lignin content, which allows the fibers to perform effectively in wet environments without rapid degradation. Furthermore, coir fibers demonstrate excellent durability and resistance to microbial attack, making them suitable for long-term applications in water treatment systems. These combined properties highlight the potential of coir fibers as a sustainable and environmentally friendly alternative to conventional synthetic filtration materials.These properties make coir suitable for filtration applications.

Table 2

Major constituents of coir fiber

Component	Percentage (%)
Cellulose	32 – 43
Hemicellulose	15 – 25
Lignin	40 – 45
Ash	0.5 – 2

The high lignin content (40–45%) contributes to superior durability compared to many other natural fibers.

4. Comparison Between Polypropylene and Coir Fiber Filters

Filtration materials play a critical role in determining the environmental sustainability and functional performance of a system. Two widely studied materials are Polypropylene (PP) and Coir Fiber, each carrying distinct characteristics rooted in their origin and processing. Polypropylene filters are synthetic, derived from petroleum-based sources through industrial manufacturing processes. While they offer moderate cost and consistent supply through industrial production, their non-biodegradable nature results in significant plastic waste upon disposal. Their high carbon footprint and limited sustainability make them an environmentally burdensome choice in the long run.

Coir fiber filters, on the other hand, are sourced from the natural biomass of coconut husks — a renewable agricultural by-product.

The comparison below highlights key parametric differences between the two materials across sustainability, cost, availability, and environmental impact dimensions.

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Table 3

Comparative Table

Parameter	Polypropylene filter	Coir fiber filter
Source	Petroleum-based	Natural biomass
Biodegradability	No	Yes
Sustainability	Low	High
Cost	Moderate	Low
Availability	Industrial production	Widely available
Disposal	Plastic waste	Environmentally friendly
Carbon footprint	High	Low

The comparison indicates that coir fibers offer significant environmental advantages over conventional polypropylene materials.

B. Why Coir Fiber Was Selected for This Study

The selection of coir fiber for this review is based on several scientific, environmental and economic considerations. First, coir fiber is abundantly available in coconut-producing countries, particularly India, Sri Lanka, Indonesia and the Philippines, ensuring a reliable and low-cost raw material supply. Second, the fiber exhibits superior durability compared to many other natural fibers due to its high lignin content, which enhances its suitability for water-related applications. Third, coir fiber supports sustainable development goals by promoting the utilization of agricultural waste and reducing dependence on petroleum-based materials. Furthermore, the growing demand for environmentally responsible water treatment technologies highlights the need to evaluate renewable alternatives capable of replacing conventional synthetic filtration media. Therefore, coir fiber represents a promising material that warrants comprehensive investigation for future water purification applications.

IV. FILTRATION MECHANISMS OF COIR FIBER-BASED WATER FILTERS

The effectiveness of any filtration material depends largely on the mechanisms through which contaminants are removed from water. In coir fiber-based filtration systems, several physical, chemical and biological processes may occur simultaneously to improve water quality. The naturally porous structure of coir fibers creates a network of interconnected voids that facilitate the retention of suspended particles and sediments. As contaminated water passes through the filtration medium, larger particles become trapped within the fiber matrix through mechanical straining, thereby reducing turbidity and improving water clarity. The rough surface texture of coir fibers further enhances particle capture by increasing the probability of contact between contaminants and the filtration media.

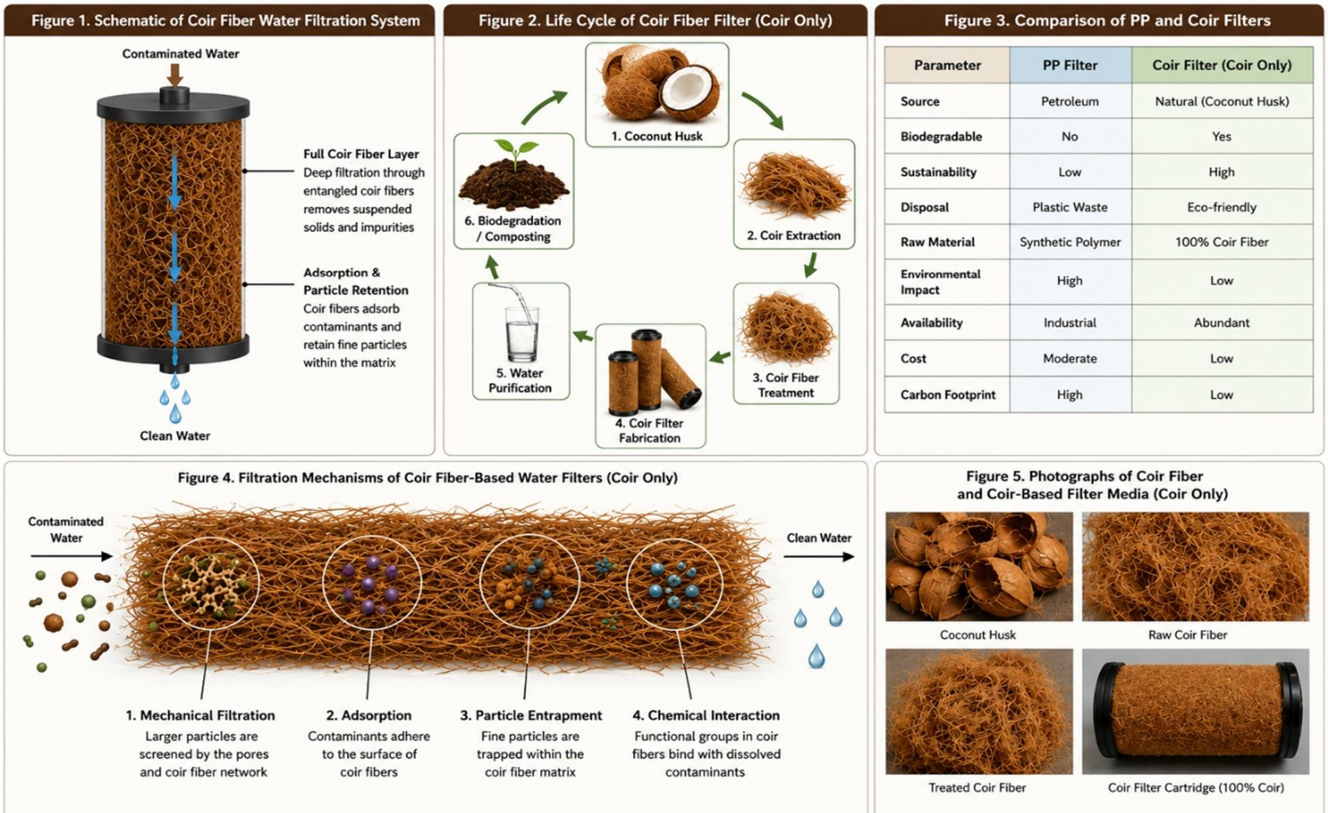
In addition to mechanical filtration, adsorption plays a significant role in contaminant removal. Coir fibers contain cellulose, hemicellulose and lignin, which provide numerous functional groups capable of interacting with dissolved pollutants. These interactions facilitate the adsorption of organic compounds, dyes and certain heavy metal ions onto the fiber surface. The high lignin content of coir fibers contributes to structural stability while also providing active sites for contaminant retention. Furthermore, surface modification techniques such as alkali treatment can increase surface roughness and improve adsorption capacity by exposing additional reactive sites. As a result, treated coir fibers may exhibit enhanced filtration performance compared to untreated fibers.

Another important mechanism is particle entrapment within the fiber matrix. As water flows through multiple layers of coir fibers, contaminants become progressively retained within the porous structure, reducing the concentration of suspended matter in the treated water. In some cases, microbial biofilms may develop on the fiber surface, contributing to biological degradation of certain pollutants. Although coir fibers alone may not provide complete removal of dissolved contaminants, their integration with activated carbon, biochar or membrane systems can significantly enhance overall purification efficiency. Therefore, the combined action of mechanical filtration, adsorption and particle entrapment makes coir fiber a promising material for sustainable water treatment applications.

Figure 2

Water purification is a systematic process that transforms raw water from natural sources such as rivers, lakes, and reservoirs into safe drinking water. The process begins with screening, where large debris like leaves and plastics are removed, followed by coagulation and flocculation, in which chemicals are added to combine fine suspended particles into larger flocs. These flocs settle during sedimentation, reducing the solid load in the water. The most significant stage in this research is **filtration using coir (coconut fiber)**, a natural, biodegradable, and sustainable material that effectively removes fine impurities, reduces turbidity, and improves water clarity due to its porous structure and high adsorption capacity. After filtration, disinfection using chlorine, UV light, or ozone eliminates harmful microorganisms, ensuring the water is safe for consumption. Corrosion control chemicals are then added to protect distribution pipelines and maintain water quality. The treated water is stored in clear water reservoirs and distributed through pipelines to homes and communities for drinking, cooking, cleaning, and other daily activities. The use of coir as the primary filtration medium offers an eco-friendly, low-cost, and renewable alternative to conventional filter materials, making it an effective solution for sustainable water treatment and environmental conservation.

Figure 3



Parameter	PP Filter	Coir Filter (Coir Only)
Source	Petroleum	Natural (Coconut Husk)
Biodegradable	No	Yes
Sustainability	Low	High
Disposal	Plastic Waste	Eco-friendly
Raw Material	Synthetic Polymer	100% Coir Fiber
Environmental Impact	High	Low
Availability	Industrial	Abundant
Cost	Moderate	Low
Carbon Footprint	High	Low

V. COMPARATIVE ANALYSIS OF NATURAL FIBERS FOR WATER FILTRATION APPLICATIONS

The search for sustainable alternatives to synthetic filtration materials has led researchers to investigate a wide range of natural fibers, including coir, jute, banana, bamboo, sisal and kenaf fibers. These materials possess several advantages such as biodegradability, renewability and low environmental impact. However, differences in chemical composition, mechanical properties and moisture resistance influence their suitability for filtration applications. Therefore, a comparative evaluation is essential for identifying the most promising candidates for sustainable water treatment systems. Among the available natural fibers, coir exhibits unique characteristics that distinguish it from other lignocellulosic materials. One of the primary advantages of coir fiber is its exceptionally high lignin content, which provides enhanced resistance to microbial degradation and prolonged durability under wet conditions. In contrast, fibers such as jute and banana possess higher cellulose content but lower lignin concentrations, making them more susceptible to degradation during long-term exposure to moisture. Bamboo fibers offer excellent mechanical strength and rapid renewability; however, their processing requirements are often more complex than those associated with coir. From an economic perspective, coir fiber represents an attractive option because it is obtained from coconut husks, which are generated in large quantities as agricultural waste. Utilizing coir fibers for water filtration not only reduces environmental burdens associated with waste disposal but also creates opportunities for value-added applications within the agricultural sector. Moreover, coir fibers can be processed with relatively simple technologies, making them suitable for low-cost water purification systems in rural and resource-limited communities. Consequently, while several natural fibers demonstrate potential for filtration applications, coir fiber offers a particularly favorable combination of availability, durability, sustainability and economic feasibility.

Fiber Modification Techniques

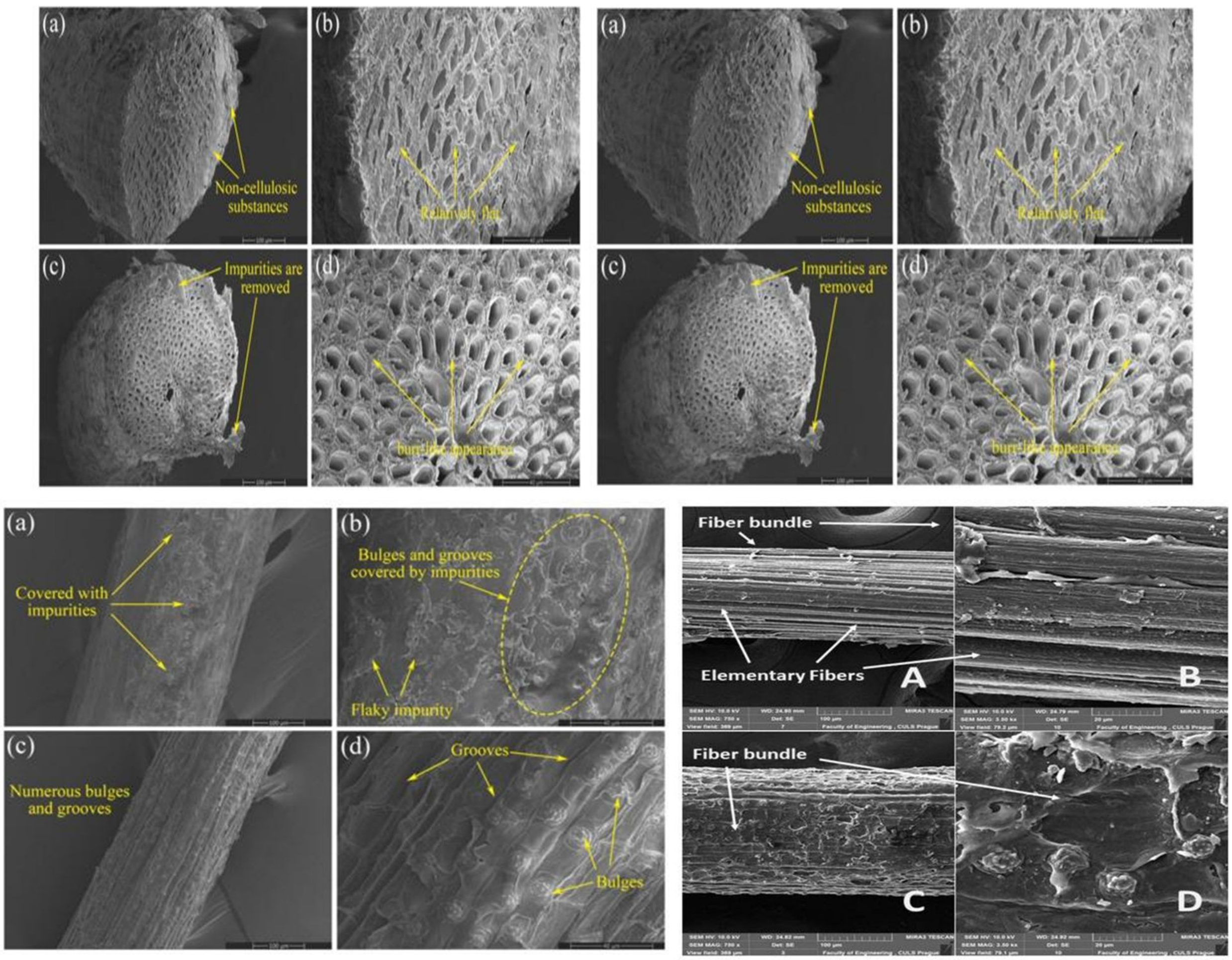
Natural fibers possess numerous advantages for water filtration applications; however, their performance can often be enhanced through appropriate modification techniques. Surface modification improves the physical, chemical and mechanical properties of fibers, thereby increasing their effectiveness as filtration materials. Various treatment methods have been explored to improve fiber-matrix interactions, increase adsorption capacity and enhance resistance to moisture-related degradation. Among these methods, alkali treatment and heat treatment are the most commonly employed techniques for improving the filtration performance of coir fibers and other natural fiber materials.

A. Alkali Treatment

Alkali treatment is one of the most widely used chemical modification techniques for natural fibers. This process involves treating the fibers with sodium hydroxide (NaOH) solution to remove impurities such as waxes, oils, hemicellulose and other surface contaminants. The removal of these components exposes the cellulose structure and increases the surface roughness of the fibers. As a result, alkali-treated fibers exhibit improved adhesion characteristics, enhanced mechanical properties and increased surface area available for contaminant adsorption. The enhanced roughness creates additional active sites for particle retention and adsorption, thereby improving filtration efficiency. Furthermore, alkali treatment can enhance the compatibility of coir fibers with other materials when used in composite filtration systems. Consequently, alkali modification has become an important pre-treatment process for developing high-performance natural fiber-based filtration media.

Representative surface modification of coir fibers following alkali treatment, showing improved roughness and enhanced adsorption sites for contaminant removal.

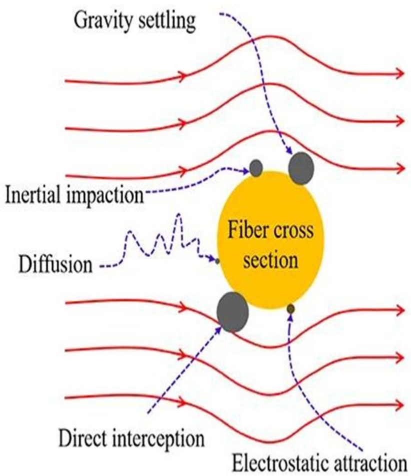
Figure 4

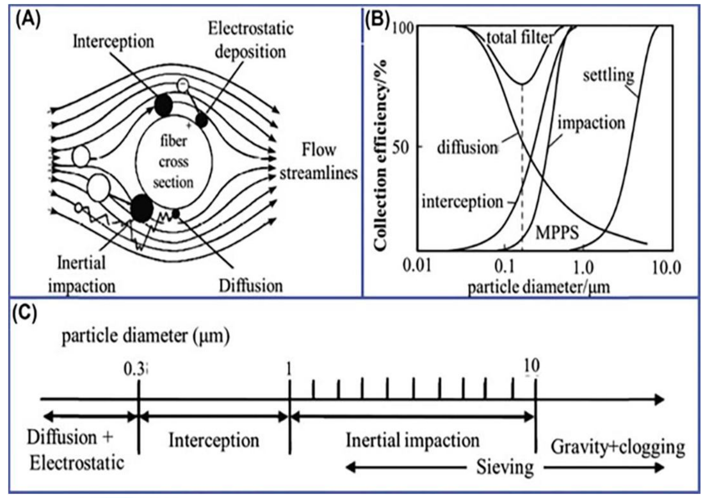


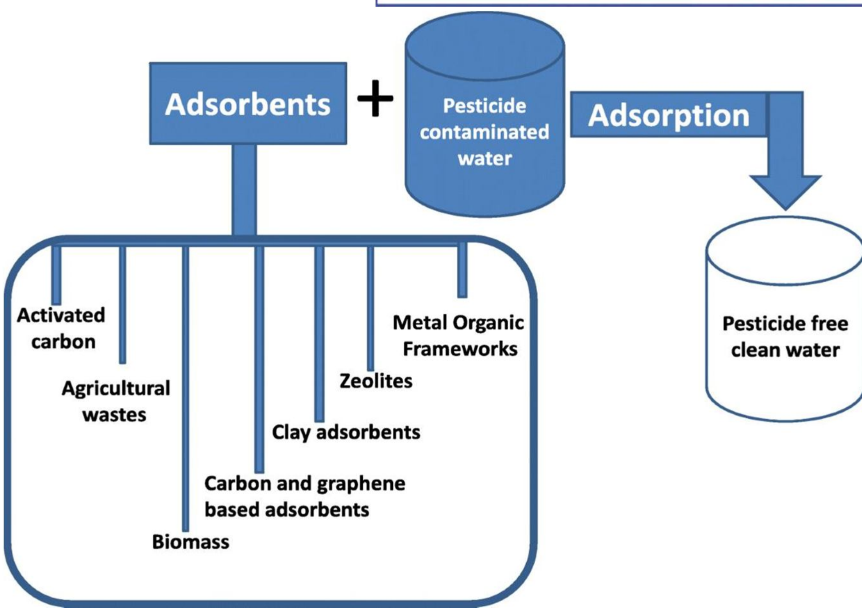
B. Heat Treatment

Heat treatment is another effective modification technique used to improve the performance of natural fibers in filtration applications. Controlled thermal treatment alters the internal structure of the fibers by reducing moisture-sensitive components and improving dimensional stability. This process enhances resistance to water absorption and minimizes swelling during prolonged exposure to moisture. Improved dimensional stability is particularly important in water filtration systems where the filtration media are continuously exposed to wet conditions. Heat-treated coir fibers often exhibit better structural integrity and durability, contributing to longer service life and more consistent filtration performance. Additionally, thermal treatment can improve the overall stability of composite filtration materials by reducing the likelihood of fiber degradation during operation.

Figure 5







VI. CHEMICAL AND THERMAL PROCESSING OF COIR FIBER FOR WATER FILTRATION APPLICATIONS

Figure 1 illustrates the sequential preparation of coir fiber prior to its application as a sustainable filtration medium. Raw coir fiber obtained from coconut husks is initially cleaned using tap water to remove adhering dust, soil particles, and organic impurities. The cleaned fibers are subsequently dried at 60–80°C until a constant weight is achieved, ensuring the removal of excess moisture and improving treatment consistency. The dried fibers are cut into predefined lengths (1, 5, and 9 cm) to investigate the influence of fiber size on filtration performance and structural stability. Alkali treatment is then performed using sodium hydroxide (NaOH) solutions at concentrations of 2%, 6%, and 10% (w/v) for 1 h under controlled agitation (150 rpm) and a liquor ratio of 1:20. The alkali treatment removes lignin, hemicellulose, waxes, and surface impurities, thereby enhancing fiber roughness, porosity, and active adsorption sites.

Following alkali treatment, the fibers are thoroughly washed with distilled water until a neutral pH (~7) is attained. Thermal treatment is subsequently carried out at 60°C, 100°C, and 140°C for 1–2 h to improve fiber stability, reduce residual moisture, and modify the physicochemical properties of the coir matrix. Finally, the treated fibers are dried and stored in airtight containers before membrane fabrication and filtration experiments.

The combined alkali and thermal modification is expected to improve contaminant adsorption, water permeability, and overall filtration efficiency of the coir-based filter.

Figure 6

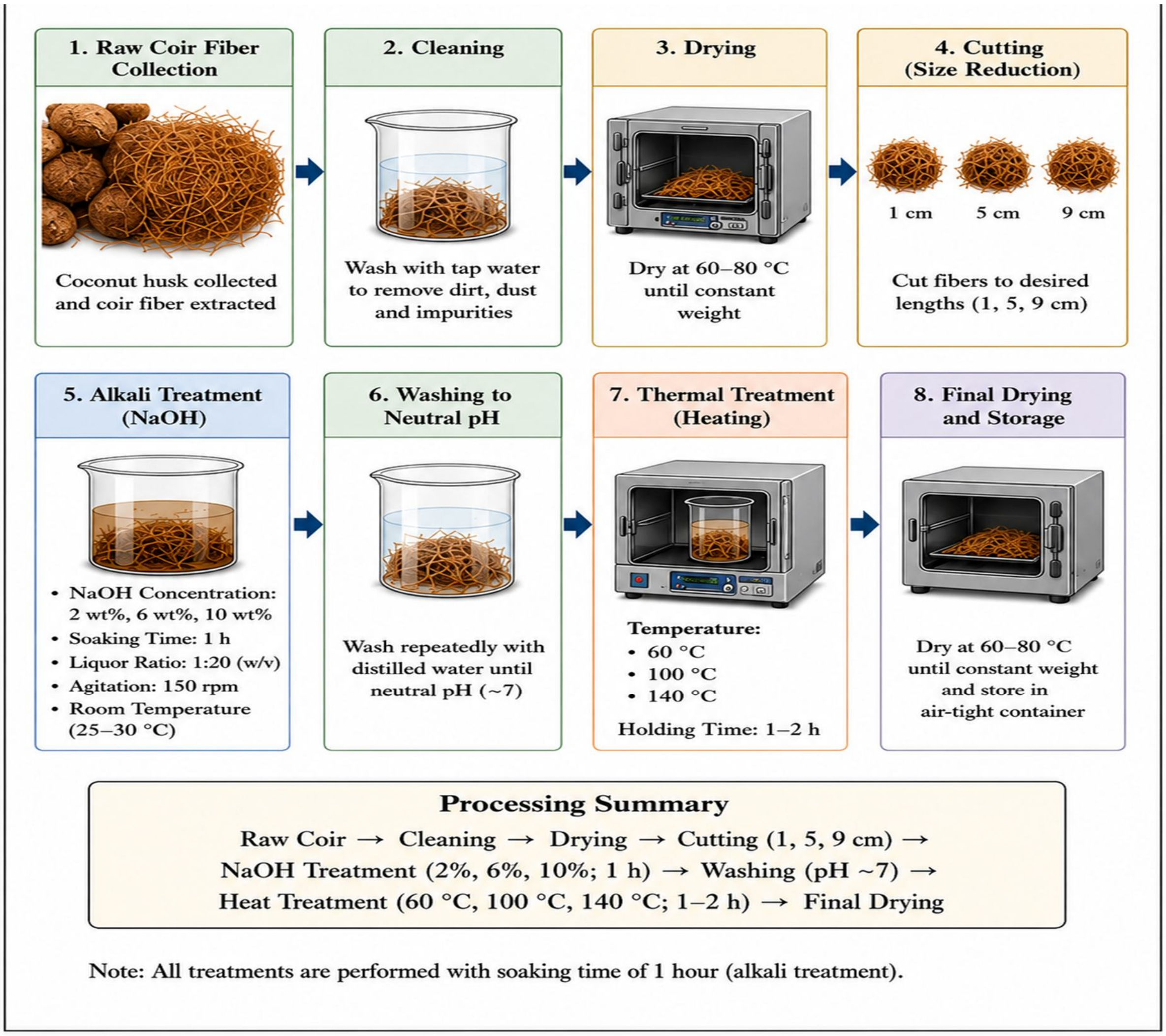
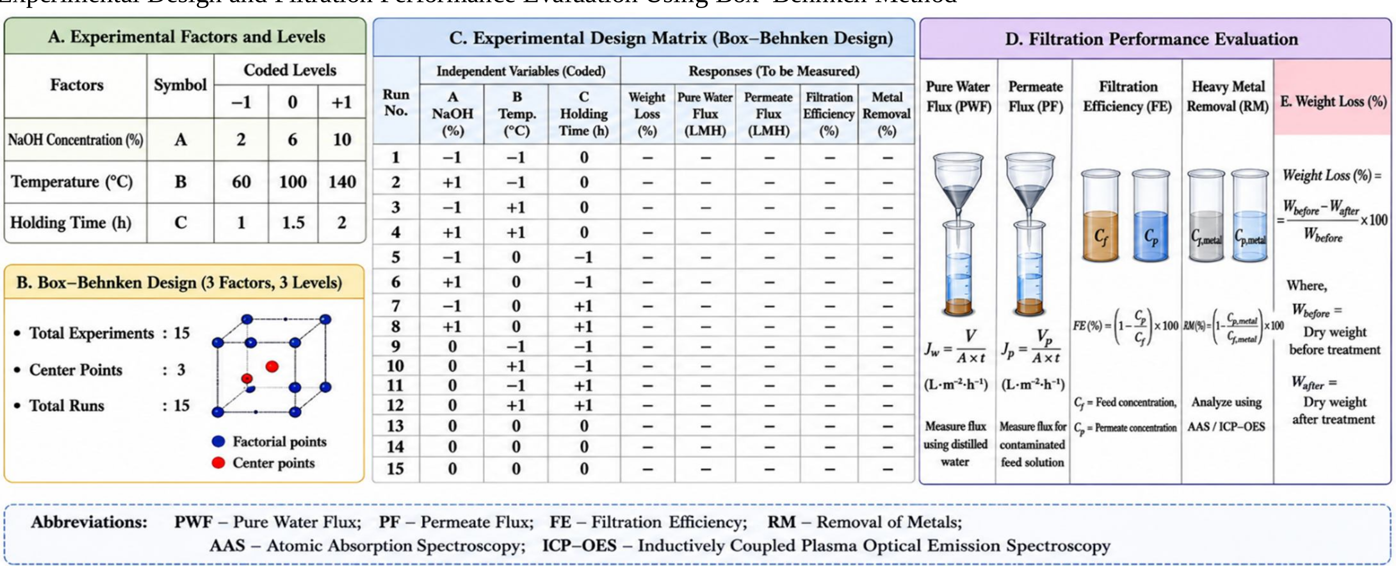


Figure 7

Experimental Design and Filtration Performance Evaluation Using Box–Behnken Method



Factors	Symbol	Coded Levels −1	0	+1
NaOH Concentration (%)	A	2	6	10
Temperature (°C)	B	60	100	140
Holding Time (h)	C	1	1.5	2

Run No.	A NaOH (%)	B Temp. (°C)	C Holding Time (h)	Weight Loss (%)	Pure Water Flux (LMH)	Permeate Flux (LMH)	Filtration Efficiency (%)	Metal Removal (%)
	Independent Variables (Coded)			Responses (To be Measured)				
1	−1	−1	0	–	–	–	–	–
2	+1	−1	0	–	–	–	–	–
3	−1	+1	0	–	–	–	–	–
4	+1	+1	0	–	–	–	–	–
5	−1	0	−1	–	–	–	–	–
6	+1	0	−1	–	–	–	–	–
7	−1	0	+1	–	–	–	–	–
8	+1	0	+1	–	–	–	–	–
9	0	−1	−1	–	–	–	–	–
10	0	+1	−1	–	–	–	–	–
11	0	−1	+1	–	–	–	–	–
12	0	+1	+1	–	–	–	–	–
13	0	0	0	–	–	–	–	–
14	0	0	0	–	–	–	–	–
15	0	0	0	–	–	–	–	–

Filtration efficiency is calculated from feed and permeate concentrations to evaluate contaminant removal capability. Heavy metal removal efficiency is determined using analytical techniques such as Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

The Box–Behnken model enables identification of the optimum treatment conditions that maximize water flux and contaminant removal while maintaining structural integrity of the coir fiber filter.

Figure 3 summarizes the characterization techniques employed to investigate the effects of alkali and thermal treatments on coir fiber properties. Mechanical, morphological, chemical, and thermal analyses are conducted to establish correlations between fiber modification and filtration performance.

1) Mechanical Characterization

Tensile strength measurements are performed using a Universal Testing Machine (UTM) to assess the mechanical stability of treated fibers. Fiber diameter is measured using optical microscopy to evaluate dimensional changes resulting from chemical and thermal processing.

2) Morphological Characterization

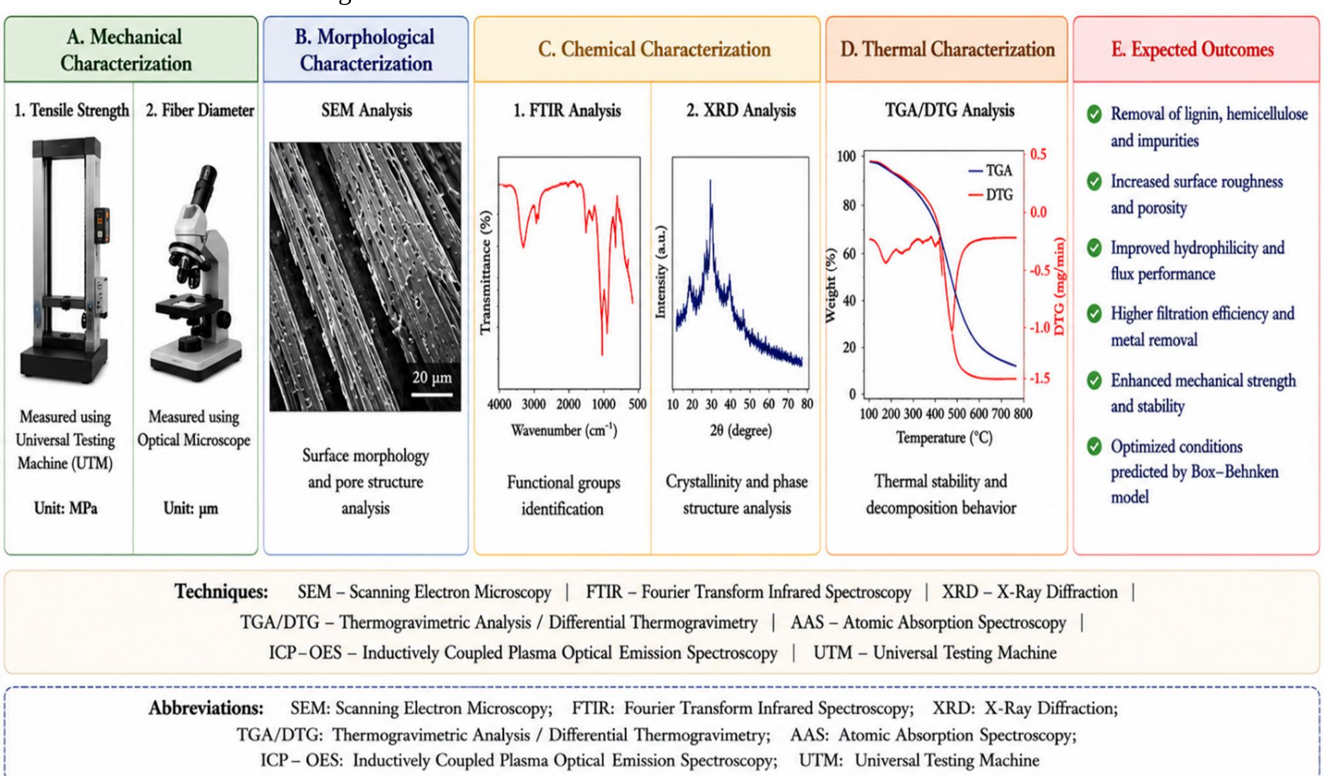
Scanning Electron Microscopy (SEM) is employed to examine surface morphology and pore structure. Alkali-treated fibers generally exhibit increased surface roughness and porosity due to the removal of surface impurities and non-cellulosic materials, which enhances adsorption and particle retention.

3) Chemical Characterization

Fourier Transform Infrared Spectroscopy (FTIR) is used to identify changes in functional groups after treatment. Reduction in characteristic lignin and hemicellulose peaks confirms successful alkali modification.

X-ray Diffraction (XRD) analysis evaluates the crystallinity of cellulose within the coir fibers. Increased crystallinity may indicate removal of amorphous constituents and improved structural organization.

Figure 8. Characterization of Alkali and Heat Treated Coir Fibers



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4) Thermal Characterization

Thermogravimetric Analysis (TGA/DTG) is conducted to determine thermal stability and degradation behavior. Treated fibers often demonstrate improved thermal resistance due to changes in chemical composition and cellulose structure.

5) Expected Outcomes

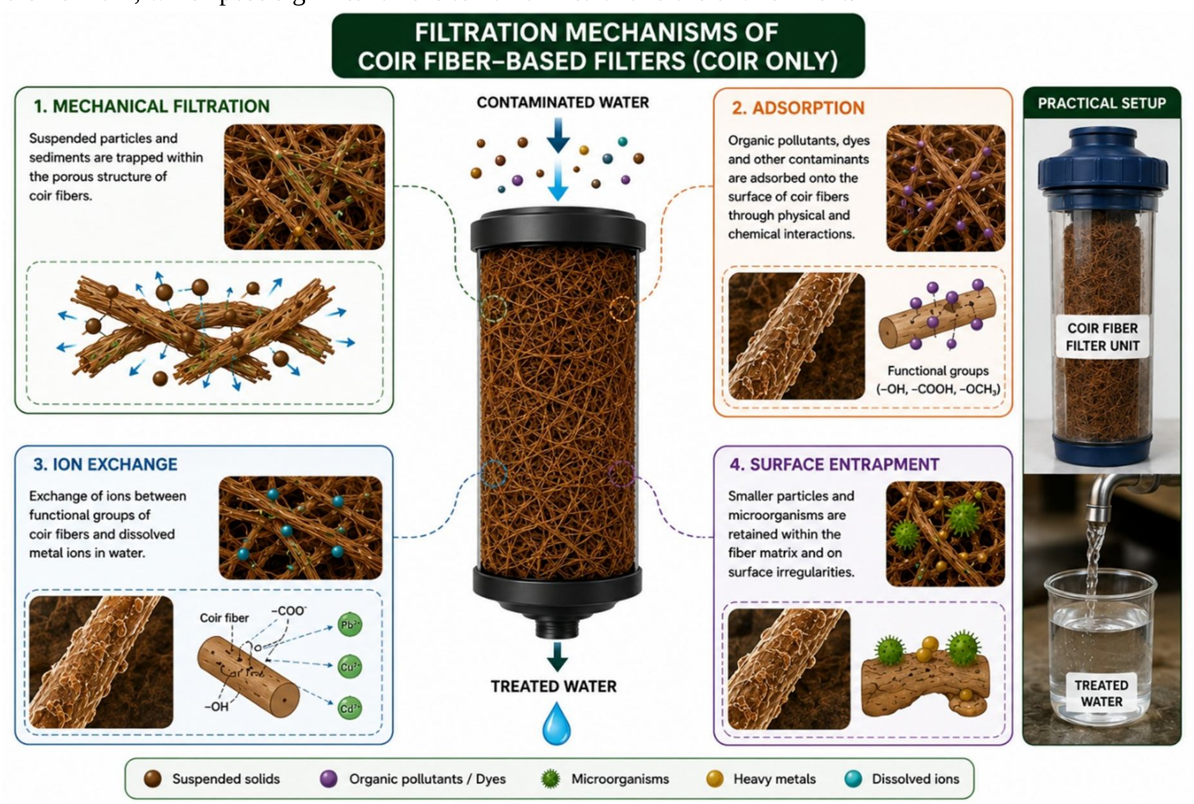
The combined alkali and thermal treatments are expected to:

- Remove lignin, hemicellulose, and impurities.
- Increase surface roughness and porosity.
- Improve hydrophilicity and water permeability.
- Enhance filtration efficiency and heavy metal adsorption.
- Improve mechanical strength and thermal stability.
- Provide optimized treatment conditions through Box–Behnken modeling.

Overall, the characterization results provide fundamental insight into the structure–property–performance relationships governing the effectiveness of coir fiber as an eco-friendly water filtration material.

A. Ion Exchange

Ion exchange mechanisms may contribute to the removal of dissolved ionic contaminants and heavy metals from water. Functional groups present within the lignocellulosic structure of coir fibers can interact with positively charged metal ions through electrostatic attraction and ion exchange processes. This mechanism is particularly important for the removal of toxic heavy metals such as lead, cadmium and chromium, which pose significant risks to human health and the environment.



B. Surface Entrapment

Surface entrapment occurs when contaminants become retained within the complex fiber matrix of the filtration material. The rough surface texture and irregular morphology of coir fibers create numerous microcavities that can trap suspended particles and impurities. As water passes through multiple layers of fibers, contaminants become progressively retained, contributing to enhanced filtration performance and improved water quality

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VII. ENVIRONMENTAL IMPACT ASSESSMENT

The increasing emphasis on sustainable development has highlighted the importance of environmentally responsible water treatment technologies. Conventional filtration materials, particularly petroleum-derived polymers such as polypropylene, contribute significantly to plastic waste generation and environmental pollution. In contrast, natural fiber-based filtration materials offer a more sustainable alternative due to their renewable origin, biodegradability and lower environmental footprint.

One of the most significant environmental advantages of coir fiber-based filters is the reduction of plastic waste generation. Unlike synthetic polymer filters, coir fibers are biodegradable and can naturally decompose at the end of their service life, thereby minimizing waste accumulation in landfills and natural ecosystems. Furthermore, coir fibers are obtained from coconut husks, an agricultural by-product that is often discarded or underutilized. Their utilization in water filtration applications supports waste valorization and promotes circular economy principles.

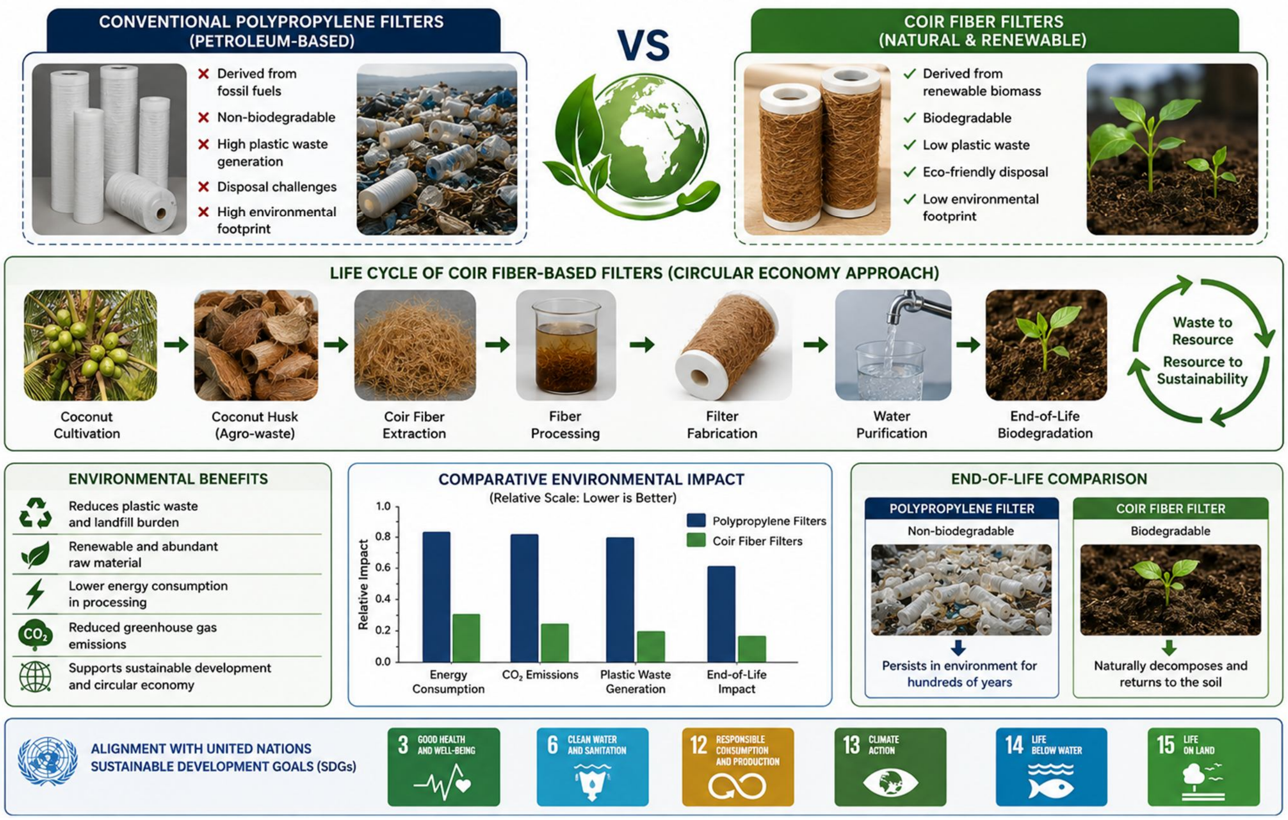


Figure 7. Environmental Impact Assessment of Coir Fiber-Based Filters

Coir fiber-based filtration materials are derived from renewable resources, require low energy for processing, and are biodegradable at the end of life, thereby reducing environmental pollution and supporting sustainable water treatment.

Another important sustainability benefit is the use of renewable raw materials. Coconut cultivation provides a continuous and abundant source of coir fibers without requiring additional land resources specifically for fiber production. This renewable nature reduces dependence on non-renewable fossil fuel resources commonly used in synthetic polymer manufacturing. Additionally, the processing of coir fibers generally requires lower energy inputs compared with the production of conventional plastic filtration materials, resulting in reduced greenhouse gas emissions and lower overall energy consumption.

The end-of-life management of filtration materials also plays a crucial role in environmental sustainability. Coir fiber filters exhibit superior biodegradability compared with polypropylene filters, allowing them to degrade naturally under appropriate environmental conditions. This characteristic significantly reduces long-term environmental impacts and contributes to more sustainable waste management practices. Consequently, life cycle assessment studies frequently indicate that natural fiber-based products exhibit lower environmental burdens than synthetic polymer counterparts, supporting their potential role in future sustainable water treatment systems.

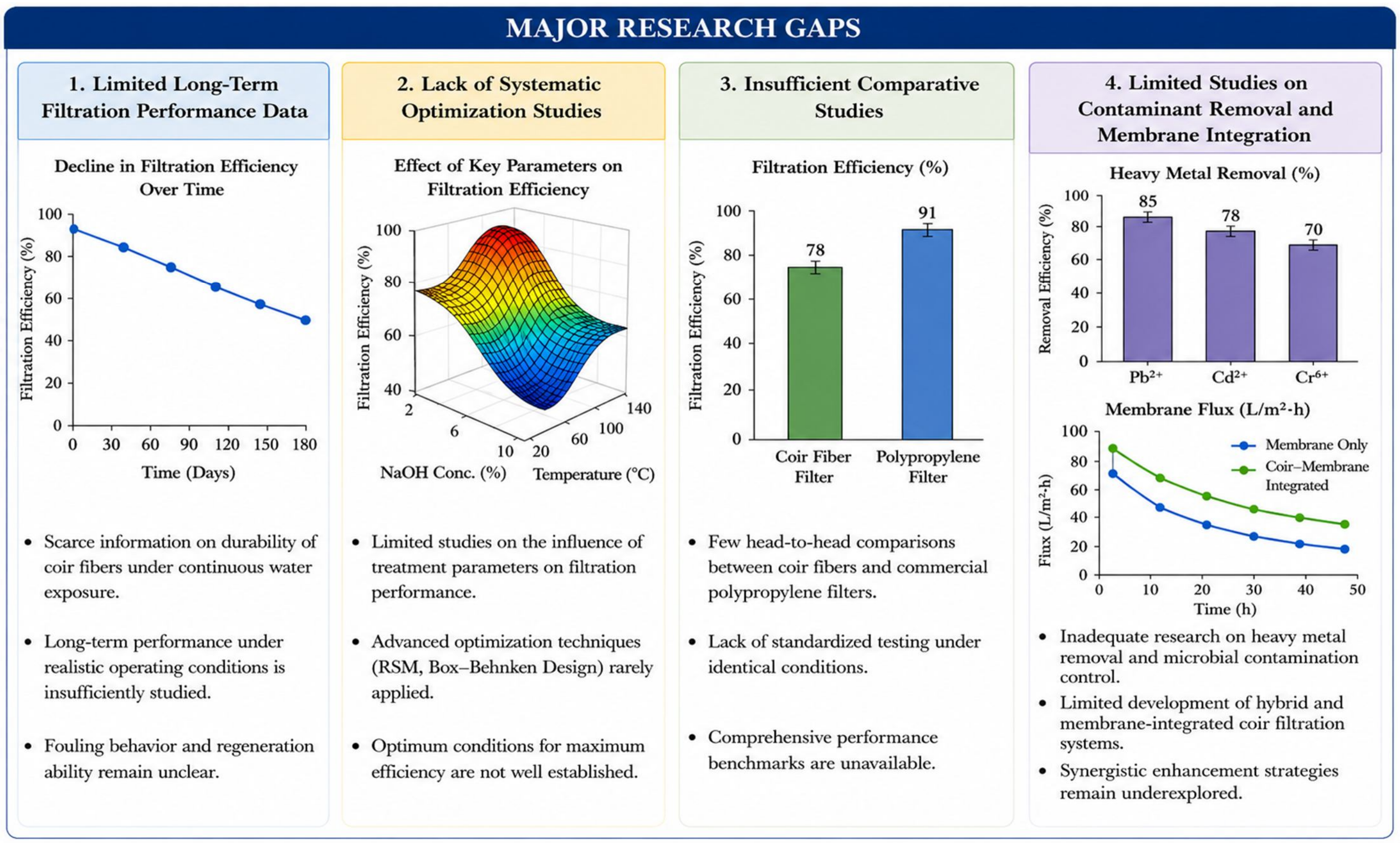
Overall, the adoption of coir fiber-based filtration materials aligns closely with global sustainability objectives and the United Nations Sustainable Development Goals by promoting resource efficiency, reducing plastic pollution and encouraging the utilization of renewable materials in environmental applications.

VIII. RESEARCH GAPS

Despite growing interest in natural fiber-based filtration materials, several important research gaps remain. Most existing studies have focused primarily on the characterization of natural fibers and their application in composite materials rather than their direct use in water purification systems. Consequently, limited information is available regarding the long-term filtration performance of coir-based materials under realistic operating conditions. In particular, the durability of coir fibers during continuous exposure to water requires further investigation.

Another significant research gap concerns the optimization of coir fiber filtration systems. Although surface modification techniques have been shown to improve fiber properties, systematic studies examining the influence of treatment parameters on filtration efficiency remain relatively scarce. Advanced optimization approaches such as Response Surface Methodology and Box–Behnken Design have rarely been applied to coir-based filtration materials. Furthermore, comparative studies evaluating coir fibers against commercial polypropylene filters under identical testing conditions are limited.

Research addressing heavy metal removal, microbial contamination control and membrane integration is also insufficient. Future investigations should focus on developing hybrid filtration systems that combine coir fibers with activated carbon, biochar, nanomaterials or advanced membrane technologies. Such approaches may significantly improve contaminant removal efficiency while maintaining sustainability benefits



IX. FUTURE SCOPE

Future research should focus on transforming coir fiber from a promising laboratory material into a commercially viable filtration medium capable of addressing global water treatment challenges. One potential direction involves the development of hybrid composites incorporating coir fibers with activated carbon, graphene derivatives, biochar and nanomaterials. These advanced materials may enhance adsorption capacity, improve mechanical stability and increase filtration efficiency.

Another promising area involves the application of statistical optimization techniques such as Response Surface Methodology and Box–Behnken Design to identify optimal fabrication parameters. These approaches can help maximize contaminant removal efficiency while minimizing material usage and production costs. Additionally, integrating coir-based filtration systems into decentralized water treatment units may provide affordable and sustainable solutions for rural communities lacking access to centralized infrastructure.

The emergence of smart filtration technologies presents further opportunities for innovation. Future systems may incorporate sensors capable of monitoring water quality and filter performance in real time. Such developments could facilitate predictive maintenance and improve overall system reliability. By combining sustainable materials with advanced engineering approaches, coir fiber-based filtration technologies may contribute significantly to future water purification strategies.

Future research should focus on:

1) Hybrid coir composite filters
2) Nanomaterial-enhanced filtration systems
3) Optimization using Box–Behnken and response surface methodologies
4) Rural water purification applications
5) Commercial-scale production

X. CONCLUSION

The increasing environmental concerns associated with polypropylene filtration materials necessitate the development of sustainable alternatives. Coir fiber possesses several advantages, including biodegradability, abundance, low cost, and favorable mechanical properties. Current evidence suggests that coir fiber has significant potential as a filtration medium for water purification applications. Further research focusing on material optimization, durability, and large-scale implementation could facilitate the transition toward environmentally sustainable water filtration technologies.

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