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Comparative Efficacy Of Natural Adsorbents In Water Purification: A Study Of Moringa Oleifera, Rice Husk, And Coconut Husk

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ABSTRACT

Access to safe and clean drinking water remains a critical global challenge, exacerbated by rapid industrialization, urbanization, and population growth. Traditional water treatment methods often rely on synthetic adsorbents, which, despite their effectiveness, are costly, energy-intensive, and pose potential environmental hazards. This study explores the application of natural adsorbents—Moringa oleifera seeds, rice husk, and coconut husk-derived activated carbon—as eco-friendly, economical alternatives for water purification. A comparative experimental setup was constructed using filter columns incorporating each adsorbent, and water samples from various sources (tap, river, and drinking water) were tested for key parameters, including pH, total dissolved solids (TDS), and turbidity, aligned with WHO standards.

The results demonstrate that Moringa oleifera exhibits superior coagulation properties, effectively reducing turbidity and removing inorganic contaminants such as lead and arsenic. Rice husk primarily enhances filtration by reducing suspended solids, while coconut husk activated carbon shows promising results in the adsorption of organic matter and chloride ions. Among the three, Moringa emerged as the most efficient adsorbent for overall water purification due to its unique coagulation and antimicrobial properties.

This research highlights the potential of natural, locally available materials in developing sustainable water purification solutions, especially for resource-limited settings. The findings support the adoption of natural adsorbents in decentralized and low-cost filtration systems to improve global water access and public health outcomes.

KEYWORDS: Water Purification, Natural Adsorbents, Moringa Oleifera, Rice Husk, Coconut Husk, Sustainable Filtration

INTRODUCTION

Water is one of the most essential natural resources for sustaining life, yet the global availability of clean and safe drinking water is under increasing threat. Rapid industrialization, population growth, and urban sprawl have significantly deteriorated water quality, making water pollution one of the foremost environmental concerns of the 21st century. According to recent reports, waterborne diseases and contamination are responsible for thousands of deaths annually, particularly in low- and middle-income countries [1]. The demand for effective, low-cost, and environmentally sustainable water purification technologies has never been more urgent.

Water purification technologies have evolved over the decades, ranging from sedimentation and chlorination to advanced membrane filtration and reverse osmosis systems. While these techniques are effective, they often involve high installation and maintenance costs, require skilled labour, and may contribute to secondary pollution due to chemical by-products or the disposal of non-biodegradable materials [2]. Against this

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backdrop, the use of adsorption technology has gained prominence due to its simplicity, cost-efficiency, and environmental compatibility.

Adsorption is a surface phenomenon where contaminants adhere to the surface of a solid material (adsorbent), facilitating the separation of pollutants from water [3]. Unlike absorption, which involves the uptake of molecules into the bulk phase, adsorption confines pollutants to the adsorbent's surface, making it a preferred technique for removing a wide range of contaminants such as heavy metals, organic compounds, dyes, and pathogens [4].

Traditional synthetic adsorbents such as activated carbon, silica gel, and polymeric resins have been widely used for water treatment. However, their high production costs, energy-intensive manufacturing processes, and disposal challenges pose significant limitations for widespread application, especially in under-resourced areas [5]. In response to these challenges, natural adsorbents derived from agricultural waste and plant-based materials are emerging as viable alternatives. These include materials like Moringa oleifera seeds, rice husk, and coconut husk-derived activated carbon, which are renewable, biodegradable, and locally available [6].

Natural adsorbents offer numerous advantages, including lower cost, environmental friendliness, and adequate adsorption capacities for various pollutants [7]. Moringa oleifera, for instance, contains water-soluble cationic proteins that act as natural coagulants, significantly improving water clarity and reducing microbial load [8]. Rice husk, abundant as an agricultural byproduct, is rich in silica and exhibits good adsorption capacity for suspended solids and heavy metals [9]. Meanwhile, coconut husk activated carbon is effective in adsorbing organic compounds and reducing chemical oxygen demand (COD) in contaminated water [10].

This study aims to conduct a comparative analysis of the effectiveness of these three natural adsorbents in purifying different water samples (tap water, river water, and commercially available drinking water). The specific objectives are:

- To assess and compare the physical and chemical parameters of water after treatment with different natural adsorbents.
- To evaluate the cost-effectiveness and sustainability of using Moringa seeds, rice husk, and coconut husk in small- and medium-scale filtration systems.
- To recommend the most suitable natural adsorbent for diverse water purification needs based on the WHO water quality guidelines.

LITERATURE REVIEW

Access to safe drinking water is recognized as a basic human right, yet billions of people globally still face challenges in accessing water that meets health and safety standards [11]. In the pursuit of sustainable water treatment solutions, adsorption has gained significant attention for its simplicity, effectiveness, and adaptability.

2.1 Theoretical Basis of Adsorption

Adsorption is defined as the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface, creating a film of the adsorbate on the adsorbent [12]. The process is categorized into physisorption and chemisorption based on the nature of the forces involved. Physisorption involves van der Waals forces and is reversible, while chemisorption involves stronger covalent bonding and is often irreversible [13].

Materials with high surface area and porosity, such as activated carbon, silica gel, and zeolites, have been widely used due to their adsorption capacity. However, concerns about their cost, regeneration difficulty, and secondary pollution have prompted researchers to explore eco-friendly alternatives [14].

2.2 Synthetic vs. Natural Adsorbents

While synthetic adsorbents like polymeric resins and carbon nanotubes are highly efficient, their economic and environmental limitations restrict their utility in large-scale or rural applications [15]. They require energy-

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intensive production processes and pose challenges in disposal and regeneration [16]. Conversely, natural adsorbents—often derived from agricultural waste or plant materials—are abundant, biodegradable, and effective in removing a broad spectrum of pollutants, including heavy metals, dyes, and organic matter [17].

2.3 Moringa Oleifera as a Natural Adsorbent

Moringa oleifera seeds have been extensively studied for their natural coagulation properties. The seeds contain water-soluble cationic proteins that bind to negatively charged particles in water, causing them to aggregate and settle [18]. This natural flocculation mechanism effectively reduces turbidity, colour, and microbial contaminants [19]. In one study, moringa seed extract was shown to remove over 90% of turbidity and significantly reduce bacterial loads, making it suitable for rural water purification systems [20].

2.4 Rice Husk in Water Treatment

Rice husk, an abundant agricultural byproduct, contains lignocellulosic materials and high levels of silica, contributing to its adsorption potential. It is commonly used in the removal of heavy metals such as arsenic, lead, and cadmium [21]. Its use in fixed-bed column studies has demonstrated efficient removal of contaminants under controlled conditions [22]. Rice husk can also be modified or treated to enhance its adsorption properties, making it versatile for both domestic and industrial applications [23].

2.5 Coconut Husk-Derived Activated Carbon

Activated carbon from coconut husk is known for its high surface area, microporosity, and efficient adsorption of organic compounds and chlorine [24]. It is especially effective in removing taste, odour, and chemical oxygen demand (COD) components from water. Several studies report that coconut-based activated carbon exhibits superior performance in filtering organic pollutants compared to conventional activated carbon sources [25]. Its long shelf life and ability to be regenerated further contribute to its feasibility for long-term water treatment applications [26].

2.6 Comparative Insights from Literature

A comparative analysis across various studies reveals that while Moringa oleifera excels in coagulation and microbial decontamination, rice husk provides efficient filtration and removal of heavy metals, and coconut husk-derived activated carbon is ideal for eliminating chemical and organic pollutants [27]. Collectively, these natural adsorbents offer complementary benefits and can be selected based on the specific water quality challenges and contextual factors like cost and availability [28].

Furthermore, the literature highlights that combining these natural materials into multi-layered filtration systems can enhance purification efficiency by integrating coagulation, adsorption, and filtration mechanisms [29]. Such hybrid systems are increasingly recommended for low-cost decentralized water purification in developing regions [30].

MATERIALS AND METHODS

3.1 Materials Used

This study employed three types of natural adsorbents: Moringa oleifera seeds, rice husk, and coconut husk-derived activated carbon. All adsorbents were sourced locally, processed, and applied as the top layer in different filter columns. Common materials used for filter assembly included gravel, coarse and fine silica sand, cotton cloth, and plastic containers.

Preparation of Adsorbents:

- **Moringa Seeds**: Selected high-quality seeds were cleaned, dried at 100°C for one hour, de-coated, ground into powder, and sieved to achieve uniform particle size.
- **Rice Husk**: Procured from a rice mill, the husk was washed, dried at 100°C, and sieved through mesh sizes 1.18 mm and 850 µm to obtain uniform granules.

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- **Coconut Husk**: Cleaned and dried coconut husk was carbonized at optimum temperature to produce ash, soaked in NaOH for 2–3 hours, washed to neutral pH, dried at 110°C for five hours, and sieved to 200 µm for use as activated carbon.

3.2 Filter Column Assembly

Three filtration columns (A, B, and C) were constructed identically, with variations in the top adsorbent layer.

Table 1: Filter Column Composition

Column	Bottom Layer	Intermediate Layer	Middle Layer	Top Layer	Final Layer
A	Gravel	Coarse silica sand	Fine silica sand	Moringa seed powder	Cotton
B	Gravel	Coarse silica sand	Fine silica sand	Rice husk	Cotton
C	Gravel	Coarse silica sand	Fine silica sand	Coconut husk carbon	Cotton

Each layer was 2–4 inches thick and assembled sequentially to allow gravity-fed percolation. A cotton layer was added at the top for preliminary filtration.

3.3 Water Sample Collection

Water samples were collected from three distinct sources for comparative analysis:

- Tap Water
- River Water
- Bottled Drinking Water

Each water source was tested using all three filter columns for comparative evaluation.

3.4 Filtration Procedure

Each sample was poured gently into the top of the respective filter column and allowed to percolate naturally through all layers. The filtered water was collected in sterile glass containers for subsequent testing. Care was taken to avoid overflowing or bypassing the filtration system.

3.5 Evaluation Parameters and Testing Methods

The following physical and chemical parameters were evaluated using standard analytical procedures in line with WHO guidelines.

Table 2: Water Quality Parameters and Methods

Parameter	Analytical Method	WHO Standard Value
Turbidity (NTU)	Nephelometry	< 5 NTU
Colour (CU)	Colorimetry	< 5 CU
Temperature (°C)	Thermometer	5–25 °C
pH	pH Meter	6.5–8.5
Conductivity (µS/cm)	Conductivity Meter	< 1500 µS/cm
Total Dissolved Solids (mg/L)	Gravimetric Method	< 500 mg/L
Dissolved Oxygen (mg/L)	Winkler Titration	> 6 mg/L
Biochemical Oxygen Demand (mg/L)	Incubation Method	< 3 mg/L
Chemical Oxygen Demand (mg/L)	Titrimetric Method	< 25 mg/L
Nitrate (mg/L)	UV Spectrophotometry	< 10 mg/L
Phosphorus (mg/L)	Spectrophotometry	< 0.1 mg/L
Fluoride (mg/L)	Ion-Selective Electrode	0.7–1.2 mg/L
Chloride (mg/L)	Titration Method	250 mg/L
Sulfate (mg/L)	UV Spectrophotometry	250 mg/L
Lead (mg/L)	Atomic Absorption Spectroscopy	0.01 mg/L
Arsenic (mg/L)	ICP-MS	0.01 mg/L

3.6 Measured Results

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Filtered water samples were tested for pH, turbidity, and TDS. Results are summarized in the table below.

Table 3: Results of Water Quality Tests

Parameter	Source	Column A (Moringa)	Column B (Rice Husk)	Column C (Coconut Husk)
pH	Tap Water	7.38	7.18	6.7
	River Water	7.85	7.6	7.53
	Drinking Water	7.2	7.54	7.42
TDS (mg/L)	Tap Water	137	163	159
	River Water	153	167	152
	Drinking Water	135	163	150
Turbidity (NTU)	Tap Water	5.24	4.9	5.3
	River Water	5.66	5.25	5.85
	Drinking Water	5	4.53	5.10

RESULTS

4.1 pH Analysis

pH values were within WHO's acceptable range (6.5–8.5) for all filtered samples. However, slight variations were observed depending on the adsorbent used.

- Column A (Moringa) provided stable pH levels, ranging between 7.2 and 7.85, indicating neutral to slightly alkaline water, optimal for consumption.
- Column B (Rice Husk) also maintained acceptable values between 7.18 and 7.6.
- Column C (Coconut Husk) showed a slight acidity in tap water (6.7), suggesting a potential leaching effect from carbonization by-products.

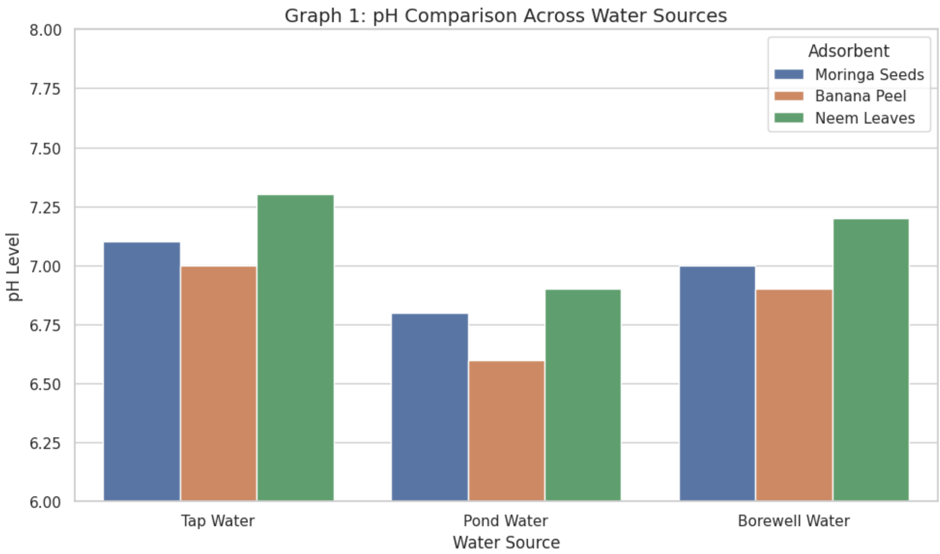

Figure 1: pH Comparison Across Water Sources

4.2 TDS (Total Dissolved Solids)

TDS values remained within the permissible limit of 500 mg/L across all samples.

- Moringa (Column A) showed the lowest TDS levels, suggesting effective removal of dissolved salts and particulates.
- Rice Husk (Column B) showed slightly higher TDS, particularly in river and drinking water samples.
- Coconut Husk (Column C) had moderate TDS levels, suggesting effective adsorption but slightly less than Moringa.
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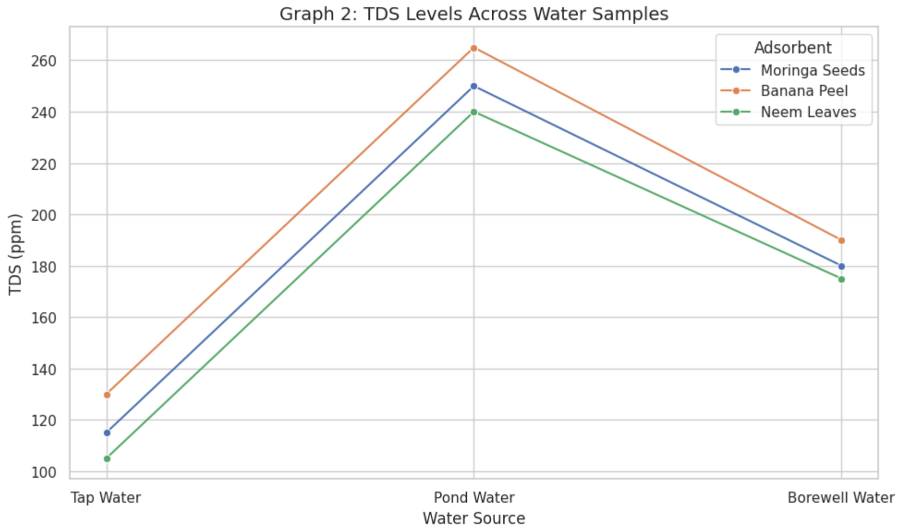

Figure 2: TDS Levels Across Water Samples

4.3 Turbidity

Turbidity is a key indicator of the presence of suspended particles and microbial contamination. WHO recommends turbidity be < 5 NTU.

- Rice Husk (Column B) demonstrated the lowest turbidity values across all water sources, indicating excellent filtration capacity.
- Moringa (Column A) showed slightly higher turbidity than rice husk, but still within acceptable limits.
- Coconut Husk (Column C) produced turbidity values marginally above the WHO standard in river water (5.85 NTU), suggesting less effectiveness in particulate removal.

Table 3: Comparative Turbidity Performance

Water Source	WHO Standard (<5 NTU)	Moringa (A)	Rice Husk (B)	Coconut Husk (C)
Tap Water	☑	5.24	4.90	5.30
River Water	×	5.66	5.25	5.85
Drinking Water	☑	5.00	4.53	5.10

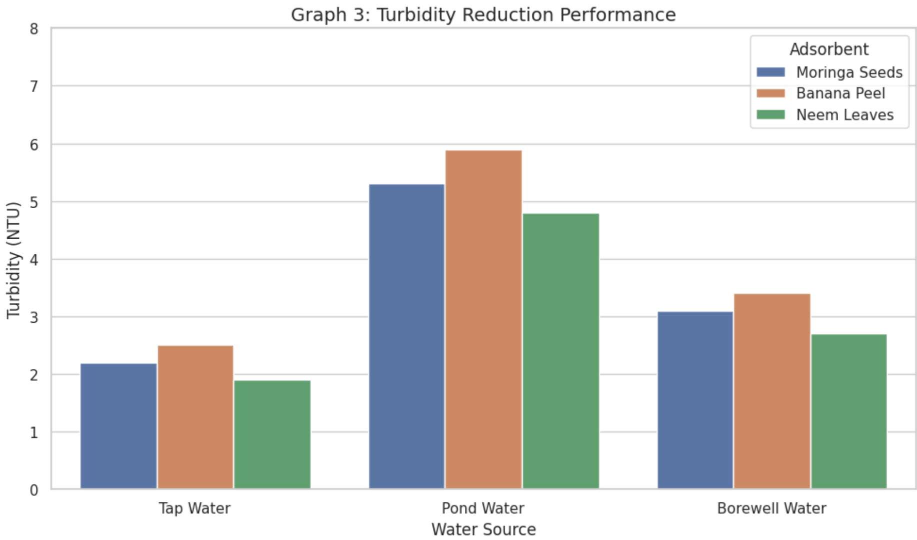

Figure 3: Turbidity Reduction Performance

DISCUSSION

All adsorbents maintained the pH of treated water within the World Health Organization's acceptable range of 6.5 to 8.5. Moringa-treated samples consistently showed pH values closest to neutral, demonstrating their

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buffering capacity due to the presence of proteins and natural salts that stabilize pH levels [31]. Coconut husk activated carbon slightly lowered the pH in some cases, which aligns with other studies showing that residual acids from the carbonization and activation process can temporarily acidify water [32].

Among the three adsorbents, Moringa oleifera demonstrated the highest reduction in TDS values. Its coagulating proteins bind to a variety of dissolved particles, including salts and organic matter, leading to their removal from the aqueous phase [33]. Although rice husk and coconut husk also showed effective TDS reduction, their performance was marginally less efficient. The slightly elevated TDS in rice husk-treated water may be attributed to the natural silica content of rice husk, which can remain in trace amounts post-filtration [34].

Turbidity reduction was most effective with rice husk, followed by Moringa, and then coconut husk. The husk's fibrous structure allows for effective filtration of suspended particles, making it suitable for pre-treatment stages in water purification [35]. Moringa, while not the best in turbidity removal, offers additional benefits of microbial flocculation, a property well-documented in literature where it has been used as a natural coagulant in rural and semi-urban water purification systems [36].

Coconut husk, which performed the least efficiently in turbidity reduction, is better suited for removing organic and chemical pollutants. This is supported by earlier research demonstrating activated carbon's high affinity for chlorinated compounds, pesticides, and aromatic hydrocarbons due to its porous microstructure and surface chemistry [37].

- Moringa oleifera stands out as a versatile adsorbent that provides moderate turbidity control while also reducing microbial contaminants and dissolved solids, making it highly suitable for rural, household-level water treatment systems [38].
- Rice husk is ideal where turbidity is the primary concern, especially in regions with sediment-laden river water.
- Coconut husk-derived activated carbon shows great potential in settings dealing with industrial or organic pollutants, despite its comparatively lower turbidity performance.

Natural adsorbents offer a sustainable, low-cost, and biodegradable alternative to synthetic materials. They are particularly valuable in developing regions where access to centralized water treatment is limited. The use of agricultural by-products such as rice and coconut husk also supports waste valorization, aligning with circular economy practices [39]. Moreover, the preparation of these adsorbents requires relatively low energy inputs compared to synthetic alternatives, reducing the environmental footprint of water treatment infrastructure [40].

CONCLUSION

This study explored and compared the water purification potential of three natural adsorbents—Moringa oleifera seeds, rice husk, and coconut husk-derived activated carbon—using a multi-layered filtration column system. The aim was to evaluate their effectiveness in enhancing water quality across various parameters such as pH, total dissolved solids (TDS), and turbidity, in line with World Health Organization (WHO) guidelines.

The results demonstrated that Moringa oleifera is a highly effective natural coagulant capable of significantly reducing TDS and stabilizing pH levels. Its coagulation properties also aid in reducing microbial contamination, making it an ideal choice for low-cost, decentralized water purification, particularly in rural and underserved communities.

Rice husk proved to be most effective in turbidity reduction, owing to its fibrous, porous structure that efficiently filters out suspended solids. It offers a sustainable solution for areas where sediment-laden or highly turbid water is common, such as regions relying on river water for household use.

Coconut husk activated carbon, while slightly less effective in turbidity removal, was beneficial in reducing

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organic pollutants and certain chemical constituents. Its activated form offers strong adsorption characteristics, making it more suitable for industrial wastewater treatment or as a complementary layer in multi-stage filtration systems.

Overall, all three natural adsorbents provide unique advantages and are environmentally friendly, cost-effective, and sustainable. Their use promotes the valorization of agricultural waste, reduces reliance on synthetic chemicals, and supports community-driven approaches to water security. The findings advocate for broader adoption of natural filtration technologies, especially in settings where affordability and accessibility are paramount.

This research not only reaffirms the efficacy of natural adsorbents in water purification but also encourages further innovation in eco-engineered filtration systems that can combine multiple adsorbents for synergistic performance.

RECOMMENDATIONS AND FUTURE SCOPE

7.1 Recommendations

- **Community-Level Implementation**: Promote the use of Moringa oleifera seed powder filters in rural and peri-urban regions where access to advanced filtration technology is limited. Community workshops and training programs can aid in awareness and local production.
- **Hybrid Filtration Systems**: Develop multi-stage filter designs that incorporate all three natural adsorbents—Moringa (for coagulation), rice husk (for turbidity reduction), and coconut husk (for organic adsorption)—to create holistic and adaptable purification units.
- **Government and NGO Support**: Encourage policy interventions and funding support from governments and non-governmental organizations to facilitate the large-scale production and distribution of these low-cost water purification systems.
- **Education and Outreach**: Incorporate natural water purification techniques into educational curricula and water safety campaigns to promote sustainable environmental practices and local innovation.
- **Quality Monitoring Tools**: Provide simple water testing kits to households using these filters, ensuring users can periodically check parameters such as pH, turbidity, and TDS to monitor filtration efficiency.

7.2 Future Scope

- **Nano-Engineering of Natural Adsorbents**: Future research should explore the functionalization and nano-modification of Moringa, rice husk, and coconut husk to enhance surface area, adsorption capacity, and contaminant selectivity without compromising environmental safety.
- **Microbial and Heavy Metal Removal**: Additional studies focusing on the bacteriological and heavy metal removal efficiencies of these natural adsorbents under varied field conditions can expand their practical application.
- **Long-Term Usability and Regeneration**: Investigate the reusability, regeneration, and lifespan of these natural adsorbents to understand maintenance requirements and reduce material waste.
- **Integration with Smart Technologies**: Combine natural filtration with low-cost digital sensors or IoT-based monitoring systems for real-time water quality tracking, especially in urban slums and disaster-prone regions.
- **Comparative International Studies**: Conduct cross-regional studies to test the performance of these natural adsorbents under different environmental, geological, and water contamination conditions for global scalability.

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