# National Science Fair Synopsis

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| **Project ID** | **NSF-SCH2025-75** |
| **Project Title** | **A Comparative Study of Water Filtration Beds** |
| **Level** | **Middle level** |
| **Category** | **Physical Science** |
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## ABSTRACT:

This study investigates the efficiency of various natural filtration media in purifying contaminated water through a comparative analysis of sand/gravel, charcoal powder, coconut fiber powder, and sugarcane bagasse powder. Each filter type (100 g) was tested under identical conditions, and key parameters such as total filtration time, visual clarity score, and Total Dissolved Solids (TDS) values were recorded. Among the tested filters, charcoal powder demonstrated the highest efficiency with a superior visual clarity score of 5 and the lowest TDS value of 107 ppm, indicating excellent removal of impurities. Sand/gravel and coconut fiber powder showed moderate effectiveness with TDS values of 593 ppm and 558 ppm respectively, while sugarcane bagasse powder achieved partial purification with a TDS value of 425 ppm. The total filtration time varied from 4 to 9.5 hours depending on the material's porosity and absorption capacity. The results suggest that charcoal powder serves as the most effective natural filter medium for water purification among the materials tested. This research supports the potential use of biodegradable and low-cost natural materials for sustainable water treatment systems.

## INTRODUCTION -

## Project Overview:

### The Quest for Clean Water

The provision of clean, safe drinking water is a critical global challenge, and understanding how to purify water is a fundamental scientific endeavor. This project outlines a simplified research plan for a comparative study of water filtration beds, demonstrating how different natural materials can be used to clean water. The experiment involves constructing four distinct filter models within a standard PVC pipe framework. The models will utilize both traditional filtration media, such as sand and charcoal, and sustainable, naturally derived materials, including dried jute and coconut fibers. This study is not merely a classroom exercise; it is an exploration of the fundamental processes behind a real-world solution to a pressing environmental and public health issue.

## Why Water Needs Cleaning:

Water from natural sources like lakes, rivers, and swamps often contains a variety of impurities. These impurities can be visible, such as dirt and debris, or invisible, such as bacteria, other microorganisms, and chemicals that can cause disease. For this reason, water from most surface sources must be treated or "cleaned" before it can be used by people. Professional water treatment plants typically employ a multi-step process that includes aeration, coagulation, sedimentation, filtration, and disinfection. This experiment will focus on the filtration stage, which is a crucial component of the larger purification process.

## The Filtration Principles:

Physical vs. Chemical Water filtration systems, even simplified homemade models, rely on fundamental scientific principles. The effectiveness of a filter is determined by the properties of the materials used and how they are arranged.

Physical Filtration: This principle involves using a physical barrier to trap and remove particles. Materials such as gravel and sand are excellent physical filters. Gravel, with its larger particle size, is typically placed at the bottom of a filter to act as a support layer and prevent the system from clogging by trapping the largest debris. Sand, particularly fine sand, has much smaller pores, allowing it to trap smaller particles that pass through the gravel layer. The fine pores of the sand allow water to pass through slowly while trapping dirt particles, leading to improved clarity.

Chemical Absorption: This principle involves using a material with a high surface area to attract and trap chemical impurities on a molecular level. Activated charcoal is a prime example of a chemical absorbent. It is a highly porous form of carbon that has an extensive surface area, allowing it to remove not only fine particles but also chemicals, odors, and unpleasant tastes that physical filters cannot. The strategic layering of these materials is not an arbitrary choice; it is a fundamental engineering principle that creates a multi-stage purification system. By placing sand and gravel layers before the activated charcoal layer, the larger particles are physically removed first. This initial filtration step prevents the more chemically active and expensive charcoal layer from becoming clogged, thus maintaining its efficiency and extending its lifespan. This layered approach, where each material serves a specific function, is a powerful and elegant method for tackling different types of water contaminants.

**EXPLORING NOVEL MATERIALS:**

**COCONUT AND JUTE FIBER -**

In addition to traditional materials, this study will investigate the use of sustainable, naturally derived materials as potential alternatives. Jute and coconut fibers are plant-based waste products that have unique properties for water filtration. The use of such materials highlights the intersection of material science, environmental engineering, and sustainable practices.

Coconut husk fragments, for instance, have been studied for use in commercial waste water treatment systems due to their unique properties. They possess both micropores and macropores, which are essential for effective treatment. Macropores facilitate efficient gas and water exchanges, while micropores provide an ideal environment for the growth of beneficial microorganisms that can assist in biological treatment. Furthermore, the high proportion of lignin in coconut fiber gives it a high mechanical resistance, allowing it to maintain its three-dimensional structure and porosity over time without compacting, a common issue with organic filtration media. The durability and porosity of these waste materials demonstrate how sustainable solutions can be both environmentally friendly and highly effective, providing a compelling real-world context for this comparative study.

## THE PROBLEM STATEMENT:

### Why Water Needs Cleaning

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## HYPOTHESES:

### Testable Predictions

Based on the scientific principles of physical filtration and chemical absorption, the following hypotheses can be formulated for this study: Hypothesis (Purity): If the filter contains activated charcoal in addition to gravel, then the filtered water will be clearer and have less odor and color than the sand- only filter. This is predicted because activated charcoal's porous structure allows it to chemically absorb impurities and odors that are too small for sand and gravel to physically trap. If the filter uses coconut fiber, then it will perform comparably to the traditional charcoal filter in terms of purity. This is predicted because coconut fiber's unique porous structure and lignin content provide both physical filtration and resistance to compaction, enabling it to act as an effective and durable filter medium.

If the filter uses coarser, less compact materials like gravel and certain fibers, then the filtration rate will be faster than those using fine sand. This is predicted because the larger spaces between the particles allow the water to pass through more quickly, whereas fine sand creates a denser barrier

## DESIGN OF STUDY:

### Variables:

- **Independent Variable:** This is the single factor that will be changed intentionally in the experiment to observe its effect. In this study, the independent variable is the **type of filtration material** used in each PVC pipe filter (Sand-Gravel, Charcoal-Gravel, Coconut-Gravel, Jute-Gravel).

- **Dependent Variables:** These are the factors that will be measured to see how they are affected by the independent variable. The dependent variables in this experiment are:
  - **Water Purity (Clarity):** The visual appearance of the filtered water.
  - **Filtration Rate:** The time it takes for the water to pass through the filter.
  - **Changes in Odor, Color, and pH:** These measurements will indicate the effectiveness of the filters at removing certain contaminants.

- **Controlled Variables:** These are all the factors that must be kept exactly the same for all trials to ensure that any observed changes are a direct result of the independent variable. The controlled variables for this study include:
  - The volume of "dirty water" used for each test.
  - The dimensions of the PVC pipe and the collection container.
  - The volume and layering order of each filter material.
  - The preparation of the materials (e.g., rinsing of sand and charcoal).
  - The ambient temperature.

## EXPERIMENTAL PROCEDURE:

### Building and Testing The Filters Materials

### Preparation:

The Foundation of a Fair Test
Before constructing the filters, all materials must be prepared to ensure a fair test. Thoroughly rinse the sand, gravel, and activated charcoal with clean tap water to remove any dust or fine particles that could contaminate the experiment. It is particularly important to rinse the charcoal, as un-rinsed charcoal can turn the water black and skew the results. For a consistent "dirty water" sample, a recipe should be followed for each trial. A recommended recipe involves mixing topsoil or dirt, a handful of human or pet hair, and a few drops of yellow food coloring into water.

### Filter Construction:

The PET Bottles of each of the four filters will be constructed. The layers must be added in the correct order to ensure the filter functions as intended.

**Base Layer:**

Begin by placing a cotton ball or a small piece of cloth at the very bottom of the PVC pipe to act as a physical barrier, preventing the filter media from falling through the drainage hole.

**Gravel Layer:**

Add a layer of gravel on top of the cloth. This layer acts as the primary support and prevents clogging by catching large debris first.

**Media Layer:**

The primary filter material is added next. For each of the four filters, this will be either sand, activated charcoal, dried coconut fiber, or dried jute fiber

**Top Layer:**

Place a piece of cloth or a strainer on top of the final layer to prevent the filter media from being disturbed when the dirty water is poured in.

**Conducting the Experiment**

Once the four filters are built, the experiment can begin. Place a clean, empty collection jar underneath the first filter pipe to collect the filtered water. Start a stopwatch and carefully pour a predetermined amount of the standardized "dirty water" into the top of the filter. Record the time it takes for the first drop of filtered water to emerge and the total time until all the water has passed through the filter. Collect the filtered water for analysis.


**Experimental Data Log**

Dirty Water: 200 ml

Tds Value. : 622 ppm

**TABULATION:**

| Filter Type | Quantity | Total Filtration Time (s) | Visual Clarity Score (1-5) | Tds value (Pre/Post) |
|---|---|---|---|---|
| Sand/ Gravel | 100 g | 4 Hrs. | 4 | 593 |
| Charcoal Powder | 100 g | 8 Hrs. | 5 | 107 |
| Coconut fiber Powder | 100 g | 9 Hrs. 30 Mins. | 4 | 558 |
| Sugarcane bagasse powder | 100 g | 6 Hrs. 42 Mins. | 4 | 425 |

**COLLECTION OF DATA:**


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## RESULTS:

The comparative study of water filtration beds using different materials—sand and gravel, charcoal, coconut fiber, and sugarcane bagasse—produced the following observations:

**Experimental Data Log**

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**Observations:**

All filters improved water clarity and reduced Total Dissolved Solids (TDS) compared to the dirty water baseline (622 ppm).

The charcoal filter produced the clearest water and achieved the lowest TDS value (107 ppm), indicating superior purification efficiency.

Coconut fiber and sugarcane bagasse filters performed moderately well, showing visual improvement but limited TDS reduction.

The sand and gravel filter worked fastest but had minimal purification effect compared to the others.

## DISCUSSION

The results clearly demonstrate that the choice of filtration material directly influences both the rate of filtration and water purity.

Charcoal Filter Performance:
The activated charcoal filter exhibited the best purification performance. Its highly porous structure and large surface area enabled chemical adsorption of impurities, removing color, odor, and dissolved solids effectively. However, this high absorption capacity also made filtration slower due to increased resistance to water flow.

Coconut Fiber and Sugarcane Bagasse Filters:
Both natural fibers showed potential as sustainable filtration materials.

Coconut fiber provided decent physical filtration but had slower water flow, possibly because its fibers compacted during use, reducing pore space.

Sugarcane bagasse, being more porous and less compact, allowed slightly faster flow and better TDS reduction than coconut fiber.
These results support the hypothesis that biodegradable waste materials can serve as eco-friendly alternatives, although further optimization is needed.

**Sand and Gravel Filter:**

This traditional filter acted mainly as a physical barrier, effectively removing larger suspended particles and improving visual clarity. However, without a chemical absorption layer like charcoal, it could not significantly lower the dissolved impurities, as seen in its small TDS reduction.

Overall, the data confirm the theoretical principles discussed earlier:

Finer materials (like charcoal) slow down filtration but increase purity.

Coarser materials (like sand and gravel) filter faster but less effectively.

Natural fibers fall in between, balancing sustainability and moderate performance.

## CONCLUSION

This comparative study of different water filtration beds reveals that:

**1.** Activated charcoal is the most effective material for water purification, producing the cleanest water with the lowest TDS levels.

**2.** Coconut fiber and sugarcane bagasse offer promising eco-friendly alternatives that can reduce water impurities while promoting sustainable reuse of agricultural waste.

**3.** Sand and gravel filters are useful for basic physical filtration, particularly as a preliminary stage before finer filtering.

**4.** The results support the hypothesis that filtration efficiency depends on both material type and particle size, with finer, more porous materials providing better purification but at slower rates.

In summary, while activated charcoal remains the best purifier, sustainable natural fibers like coconut and sugarcane bagasse represent an exciting direction for developing low-cost, environmentally friendly water filters that could benefit communities with limited access to commercial filtration systems.

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