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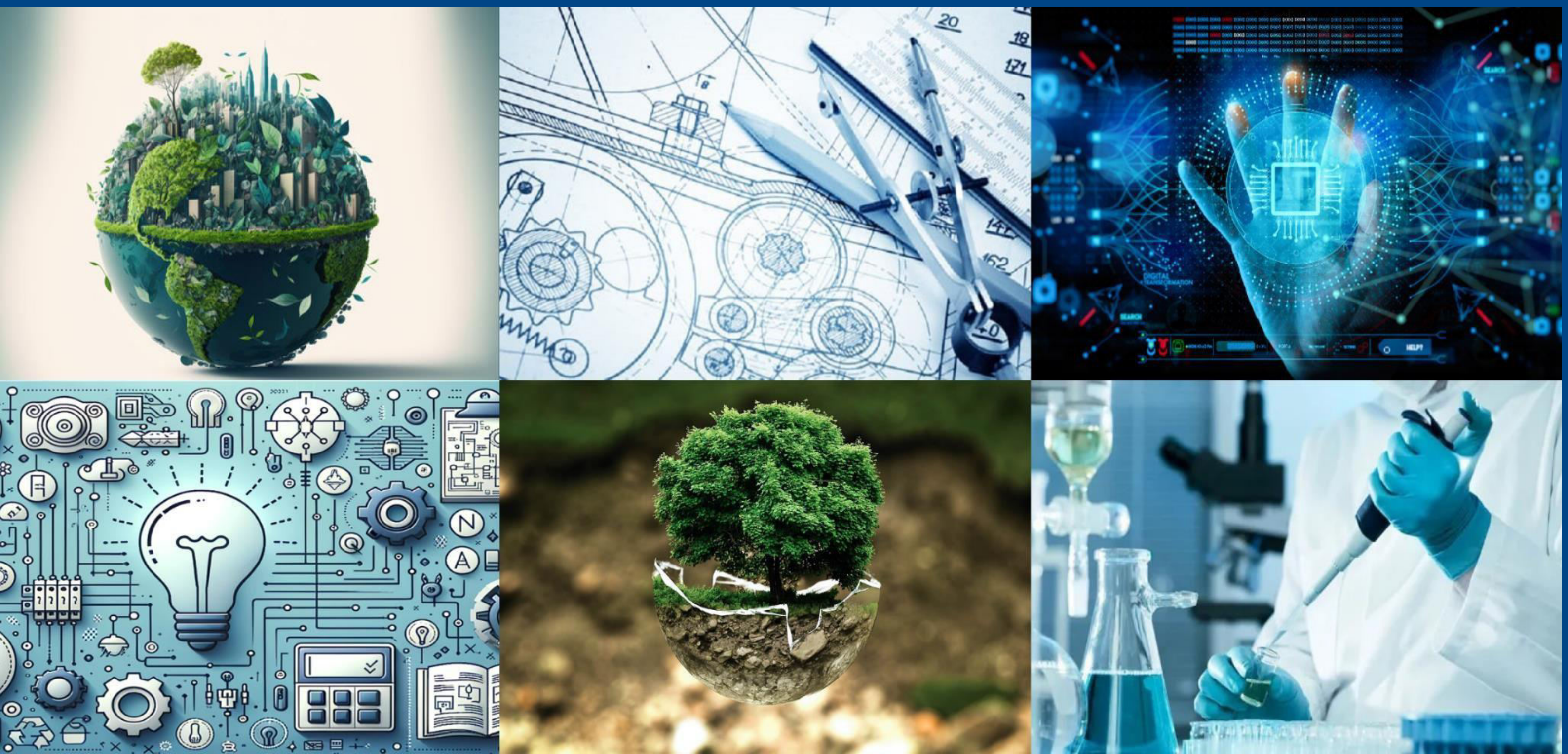

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Design of a Low-Cost Water Purification System using Natural Filters

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ABSTRACT: This paper presents the design and development of a low-cost water purification system utilizing natural filters such as neem leaves, tulsi leaves, rice husk, and sand to provide an economical, eco-friendly, and efficient solution for clean drinking water, especially in rural and remote areas. The system focuses on removing physical, chemical, and biological contaminants without the need for electricity, making it suitable for resource-limited settings. Testing of water samples before and after filtration shows significant reduction in harmful impurities, demonstrating its effectiveness and potential for rural health improvement. The lack of access to clean and safe drinking water remains a critical issue in many rural and underserved regions worldwide. Conventional water purification systems often entail high operational costs, complex technologies, and energy requirements that limit their usability in low-resource areas. This research presents the design and evaluation of a low-cost water purification system employing natural filter materials such as neem leaves, tulsi leaves, rice husk, sand, and charcoal. These materials are selected for their local availability, antimicrobial properties, and efficacy in removing physical, chemical, and biological contaminants from water. The system operates on gravity-driven multi-layer filtration, effectively reducing turbidity, pathogenic bacteria, and harmful chemicals like fluoride. Comprehensive water quality analysis before and after filtration indicates significant improvement in potable water standards. The proposed system offers a sustainable, energy-independent, and eco-friendly alternative for rural communities, with potential scalability and adaptability. This study contributes to advancing affordable water purification technologies aligned with public health and environmental sustainability goals.

KEYWORDS: Low-cost water purification, natural filters, neem leaves, tulsi leaves, rice husk, eco-friendly, rural water treatment, non-electric filtration.

I. INTRODUCTION

Access to clean and safe drinking water is a fundamental human need and essential for maintaining good health. However, in many rural and remote areas globally, especially in developing countries, safe drinking water remains scarce due to a lack of infrastructure, technology, and affordability. Contaminated water sources expose millions to waterborne diseases such as diarrhea, cholera, and dysentery, which significantly impact public health. Traditional water purification methods, including chemical treatment, boiling, or advanced filtration, often require electricity, continuous maintenance, or expensive equipment, rendering them impractical for low-income rural communities. To address this challenge, natural filtration systems using locally available materials offer an affordable, sustainable, and easy-to-operate solution. Materials like neem leaves, tulsi leaves, sand, rice husk, and charcoal have demonstrated antimicrobial, adsorptive, and sedimentation properties, making them effective in removing pathogens, turbidity, and chemical contaminants. Low-cost gravity-based water purifiers based on these natural filters can operate without electricity, are environmentally friendly, and empower communities to produce potable water safely at the household level. This research investigates the design, development, and performance evaluation of such a natural filter-based purification system, focusing on its feasibility for rural deployment, contaminant removal efficiency, and overall impact on water quality improvement. By leveraging

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indigenous knowledge and sustainable materials, the system aims to provide a practical alternative that addresses water quality challenges while promoting health and socio-economic benefits within resource-constrained settings.

II. LITERATURE REVIEW

Water purification using natural materials has been extensively studied as a viable, eco-friendly, and cost-effective approach to address water quality issues, especially in rural and low-resource settings. Various natural substances such as neem leaves, tulsi leaves, rice husk, charcoal, coconut shells, banana peels, and moringa seeds have been researched for their physicochemical and antimicrobial properties that contribute to contaminant removal from water. Recent research highlights multi-stage integrated filtration systems that combine natural filter media with functionalized sand layers and ceramic elements to enhance contaminant removal, particularly heavy metals like chromium and arsenic, as well as microbial pathogens. These systems leverage gravity-driven filtration, making them energy-independent and practical for community and household use in rural areas. Studies on home water purification devices demonstrate significant reduction of fluoride, bacterial contamination, and other chemical impurities using natural and low-cost filtration materials. Filters such as silver-impregnated porous pots and ceramic candles have shown 90-100% removal efficiencies of fluoride and microbial loads, underscoring the potential of natural filtration technologies to improve drinking water safety without complex infrastructure. Natural purification processes work through mechanisms such as sedimentation, filtration, precipitation, sorption, ion exchange, and biodegradation. Surface and groundwater treatment using sand layers and organic materials promote removal of suspended solids, organic pollutants, and microbial contaminants, making these traditional and natural methods valuable for water treatment in remote areas. Additionally, waste materials like rice husk ash, peanut shells, and pomegranate peels have been utilized to produce activated carbon and adsorbents that effectively eliminate physical, chemical, and heavy metal contaminants. These locally available materials provide sustainable and environmentally friendly alternatives to conventional activated carbon filters and support community-level water purification. A review of water purification practices emphasizes the integration of renewable energy sources, such as solar power, with natural low-cost filters to expand the usability of these systems where electricity is unavailable. Solar-driven purification can enhance pathogen inactivation and overall water quality, offering holistic and adaptable solutions for rural clean water access.

III. PROBLEM STATEMENT

Access to clean and safe drinking water remains a significant challenge, particularly in rural and low-income regions of developing countries. Millions of people rely on contaminated surface water, shallow wells, and groundwater sources that are often polluted with physical, chemical, and biological impurities. This contaminated water leads to widespread waterborne diseases including diarrhea, cholera, and dysentery, which disproportionately affect vulnerable populations such as children and the elderly. The existing water purification technologies, including reverse osmosis, ultraviolet treatment, and chlorination, are often expensive, energy-intensive, and require complex infrastructure and skilled operation. Such systems are typically unavailable or unaffordable in rural settings, where electricity supply is unreliable and maintenance services are limited. Furthermore, chemical disinfectants sometimes cause secondary contamination and adverse health effects.

IV. METHODOLOGY

The methodology for designing a low-cost water purification system using natural filters involves several systematic steps including material selection, prototype design, construction, and testing to evaluate filtration efficiency.

1. Selection of Natural Filter Materials: Locally available natural materials with known filtration and antimicrobial properties are chosen. These typically include neem leaves, tulsi leaves, rice husk, coarse sand, fine sand, gravel, and charcoal. Each material serves a specific purpose: neem and tulsi for antibacterial effects, rice husk and charcoal for adsorbing impurities, and sand and gravel for physical filtration of suspended particles.
2. Prototype Construction: The filter is assembled by fitting the layered media into the container securely, ensuring that water can percolate through the layers without bypass. The outlet at the bottom allows filtered water collection. Materials like gauze or fine mesh are used to hold the layers in place.
3. Water Sample Collection: Samples of raw water from local surface sources or bore wells are collected for testing. Parameters such as turbidity, pH, fluoride concentration, total dissolved solids (TDS), and bacterial contamination are measured before filtration to establish baseline water quality.

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4. Filtration Process: Raw water is poured onto the top of the filter system and allowed to pass through the layers by gravity. Multiple samples of filtered water are collected over several filtration cycles.
5. Water Quality Analysis: Filtered water samples are analyzed using standard water testing kits and laboratory tests to evaluate improvements in turbidity, microbial load reduction, fluoride levels, and other chemical parameters. Effectiveness is assessed based on reductions in contaminants compared to the raw water samples.

V. OBJECTIVES

- To develop a prototype of a low-cost water purification system utilizing natural and locally available filtering materials such as neem leaves, tulsi leaves, rice husk, sand, and charcoal.
- To evaluate the effectiveness of natural filter materials in removing physical impurities, microbial contaminants, and chemical pollutants including fluoride and heavy metals from raw water.
- To optimize the design configuration and layering of natural filter media for improved filtration efficiency and water flow rate.
- To assess the sustainability, affordability, and practicality of the system for rural household use without reliance on electricity or complex maintenance.
- To compare pre- and post-filtration water quality parameters such as turbidity, pH, total dissolved solids (TDS), bacterial load, and fluoride concentration to quantify purification performance.
- To promote community awareness and adoption of natural filtration technology as a sustainable approach to improve access to safe drinking water in underserved areas.

VI. WORKING

The low-cost water purification system using natural filters operates primarily on the principle of gravity-driven multi-stage filtration, where raw water passes sequentially through various natural filter media that remove different contaminants through physical, chemical, and biological processes.

- Gravity Flow: Water is poured into the top of the filtration unit, which is typically a container layered with natural materials. Gravity causes the water to percolate down through each layer without the need for pumps or electricity.
- Sedimentation and Physical Filtration: Initially, the coarse layers such as gravel and coarse sand trap larger suspended particles, sediments, and debris by physically blocking or settling them out of the water.
- Adsorption and Chemical Filtration: Charcoal and rice husk layers act as adsorbents, binding chemical pollutants, heavy metals, and organic compounds. Activated charcoal has a porous structure that traps contaminants through surface adsorption and ion exchange, improving taste and odor.
- Antimicrobial Action: Neem and tulsi leaves, rich in natural antibacterial compounds, inhibit the growth of pathogenic bacteria and viruses, reducing microbial contamination. This biological filtration layer adds a disinfecting effect without harmful chemicals.
- Fine Filtration: Fine sand ensures removal of smaller suspended particles and turbidity by filtering out fine sediments and impurities that escaped earlier layers.

VII. ADVANTAGES

1. Cost-Effective: Utilizes inexpensive, locally available natural materials such as neem leaves, tulsi leaves, rice husk, and sand, making the system affordable for rural and low-income communities.
2. Environmentally Friendly: Avoids use of chemical disinfectants and energy-intensive technologies, thereby reducing environmental pollution and carbon footprint.
3. No Electricity Required: Operates on gravity-driven filtration, making it suitable for areas without reliable power supply or infrastructure.
4. Effective Contaminant Removal: Can significantly reduce turbidity, physical suspended solids, bacteria, viruses, and some chemical pollutants, including fluoride and heavy metals, improving water quality and safety.
5. Health Benefits: Reduces risk of waterborne diseases by removing pathogens and harmful contaminants; natural antimicrobial properties of neem and tulsi add an extra layer of safety.
6. Improves Taste and Odor: Charcoal and natural materials adsorb chlorine, organic compounds, and other substances responsible for unpleasant taste and smell, enhancing water palatability.

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VIII. FUTURE SCOPE

- Integration with smart monitoring: Develop low-cost, sensor-enabled variants of the natural filter system to monitor flow rate, turbidity, and microbial indicators in real time, enabling timely maintenance and performance optimization.
- Hybridization with renewable energy: Pair gravity-driven natural filters with solar-powered disinfection to enhance pathogen inactivation without relying on grid electricity.
- Advanced natural media development: Explore biochar enhancements, locally sourced biomass-derived adsorbents, and nano- or micro-structured natural media to improve adsorption capacity and selectivity for contaminants such as fluoride, arsenic, and heavy metals.
- Standardization and quality assurance: Create simple, low-cost testing protocols for households to verify post-filtration water quality (turbidity, pH, basic microbial indicators) to ensure consistent safety across diverse settings.
- Community-scale implementations: Scale from household units to village-level kiosks or community filters, with standardized designs and maintenance plans that maximize throughput while preserving the low-cost and low-resource advantages.
- Materials circularity and sustainability: Emphasize reuse and safe disposal of spent media (e.g., regeneration of media, biochar lifecycle, and composting strategies) to reduce waste and environmental impact.
- Behavioral and training aspects: Develop user-friendly guidelines, local training modules, and maintenance schedules that fit cultural practices and literacy levels, maximizing adoption and sustained use.

IX. CONCLUSION

The design and development of a low-cost water purification system using natural filters demonstrates an effective, sustainable approach to addressing the critical challenge of safe drinking water access in rural and underserved areas. By utilizing locally available materials such as neem leaves, tulsi leaves, rice husk, sand, and charcoal, the system offers a practical, eco-friendly solution that requires no electricity and minimal maintenance. Testing indicates that the natural filter layers work synergistically to significantly reduce turbidity, microbial contaminants, and chemical impurities including fluoride, improving water quality to meet potable standards. This gravity-based, multi-stage filtration system combines physical filtration, chemical adsorption, and antimicrobial effects into a simple, cost-effective water purification option. The ease of construction, affordability, and use of renewable and biodegradable materials make this system scalable and particularly suited for resource-limited settings. It can contribute meaningfully to enhancing public health by minimizing waterborne diseases while encouraging sustainable water practices. Although more research is needed to optimize filter configurations and incorporate additional treatment stages such as solar disinfection, this natural filter system represents a promising technology for rural water purification. Its deployment could substantially improve water security and quality, empowering vulnerable communities and supporting global efforts toward universal access to safe drinking water. This conclusion summarizes the key benefits, effectiveness, and sustainability of the natural filter water purification system while acknowledging future research directions

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