Banapure: A Portable Banana Peel Ecofilter for Clean Water Needs in Survival and Emergency Conditions

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ABSTRACT
Access to safe drinking water in remote, rural, and emergency settings remains a critical global challenge. Conventional water treatment systems are costly, complex, and inaccessible in resource-limited environments, necessitating the development of low-cost, locally sourced filtration alternatives. This study presents Banapure—a portable, multi-stage ecofilter constructed from biodegradable and locally available natural materials, with banana peel (Musa spp.) as its principal biosorbent component. The Banapure system incorporates sequential filtration layers comprising a sponge pre-filter, coconut shell fiber, activated charcoal, carbonized banana peel, fine sand, gravel, and cloth fabric, housed within a bamboo receptacle to eliminate microplastic contamination associated with conventional plastic-based filters. Performance was evaluated through physical and chemical water quality parameters including color, odor, turbidity, pH, and filtration flow rate, using 250 mL contaminated water samples. Results demonstrated that the Banapure filter effectively transformed turbid, malodorous water (pH 5.6) into clear, odorless water with a near-neutral pH of 7.2, within a filtration time of approximately 7 seconds per 250 mL, with a volumetric recovery of 240–245 mL. The heavy metal adsorption capacity of the banana peel biosorbent is attributed to its carboxyl (–COOH), hydroxyl (–OH), and amine ($-NH_2$) functional groups, which form coordination bonds with divalent heavy metal cations including Pb^{2+}, Cd^{2+}, Cu^{2+}, and Zn^{2+}. A comparative analysis against commercial portable pump filters confirmed Banapure's superior environmental sustainability, negligible production cost, and practical utility in low-resource field conditions, despite reduced pathogen removal capability relative to advanced synthetic filters. These findings establish Banapure as a viable, eco-friendly solution for emergency and outdoor water purification.

1. INTRODUCTION

Access to safe drinking water remains one of the most pressing global public health challenges of the 21st century. A study by UNICEF (2022) reports that approximately 70% of drinking water sources in Indonesia are contaminated with fecal coliforms and other pathogenic microorganisms, posing severe health risks to rural and remote communities [1]. Although wastewater can theoretically be remediated through appropriate treatment processes, conventional centralized water treatment systems are expensive, energy-intensive, and infrastructurally demanding, rendering them largely inaccessible in resource-constrained or geographically isolated settings [2, 3]. This has stimulated significant scientific interest in the development of low-cost, locally sourced, and decentralized filtration technologies using natural biosorbent materials [4, 5].

Clean water access is particularly critical in outdoor, survival, and emergency scenarios, where individuals may be exposed to contaminated surface water sources including rivers, lakes, and stagnant ponds. While commercially produced bottled water and synthetic portable filters remain the predominant solutions, these options are neither universally accessible nor environmentally sustainable. There is thus a compelling need for a portable, biodegradable, and organically derived water filtration device suitable for use in natural environments without reliance on synthetic chemicals or industrial processes [6, 7].

This study presents Banapure—a portable multi-stage ecofilter that addresses this need through the innovative application of carbonized banana peel (Musa spp.) as a primary biosorbent medium. The selection of banana peel is grounded in well-documented evidence of its high adsorption capacity for heavy metals and organic contaminants, attributed to the abundant carboxyl, hydroxyl, and amine functional groups present on its surface [8]. By integrating banana peel within a sequential multi-layer filtration system housed in bamboo—a renewable, biodegradable, and microplastic-free container—Banapure offers a genuinely sustainable alternative to conventional plastic-cased commercial filters [9, 10].

The Banapure filtration system operates through gravity-driven sequential flow across multiple functional layers: a sponge pre-filter, coconut shell fiber, activated charcoal, carbonized banana peel, fine sand, gravel, and a polishing cloth layer. Each component fulfills a distinct and complementary purification role, collectively addressing turbidity, color, odor, chemical contamination, and heavy metal removal [11, 12]. The device requires no electrical power, chemical reagents, or technical expertise to operate, making it highly suitable for field deployment.

This study aims to (1) describe the fabrication and assembly of the Banapure ecofilter using exclusively natural, biodegradable, and locally available materials; (2) evaluate its filtration performance through physical and chemical water quality parameters; and (3) comparatively assess its performance relative to commercially available portable filtration systems. The findings are expected to contribute to the development of eco-friendly, accessible, and field-deployable water purification technologies aligned with sustainable development principles.

2. RESEARCH METHOD

2.1 Materials

All materials used in the fabrication and testing of the Banapure ecofilter were selected based on their documented water treatment properties, local availability, biodegradability, and cost-effectiveness. Table 1 provides a complete inventory of materials with their respective quantities and designated functions within the filtration system.

The following materials were employed in the construction and experimental evaluation of Banapure:

Table 1. complete inventory of materials

Material	Quantity	Primary Function in Filtration System
Gravel	155 g	Structural support; promotes drainage and pre-settlement of coarse particles
Fine Sand	100 g	Deep-bed filtration; principal turbidity reduction and fine particle capture
Coconut Shell Fiber	15 g	Secondary particle filtration; natural organic matter retention
Activated Charcoal	20 g	Adsorption of chemical impurities, dissolved organic compounds, residual chlorine, color, and odor
Dried Banana Peel (Carbonized Fiber)	20 g	Biosorption of heavy metals and dissolved organics; turbidity reduction
Sponge	1.2 g	Pre-filtration of large suspended particles; flow rate stabilization
Cloth Fabric (6 layers)	6 layers	Polishing layer; final micro-contaminant removal before clean water discharge
Bamboo Container	24 cm × Ø6 cm	Filter housing; eliminates microplastic leaching associated with plastic casings
Contaminated Water Sample	250 mL	Test sample (turbid surface water) for performance evaluation

Measurement and processing instruments included a calibrated digital pH meter (±0.01 accuracy) for water acidity monitoring, a stopwatch for filtration flow rate measurement, an air fryer for controlled banana peel desiccation, beakers (250 mL) for sample collection and measurement, and a spatula for gentle sample homogenization prior to filtration trials.

2.2 Banana Peel Preparation

Banana peels (Musa spp.) were collected from fresh, ripe bananas and subjected to a standardized preparation protocol. Peels were first washed thoroughly under running water to remove surface residues and then cut into uniform strips of approximately 2–3 cm width. The strips were subsequently dried in an air fryer at 100°C for 30 minutes to achieve a moisture content below 10%, followed by manual carbonization and mechanical crushing to produce a fibrous, high-surface-area biosorbent material. This preparation method is consistent with documented procedures for maximizing the density of active functional groups on the biosorbent surface [2].

2.3 Filter Assembly

The Banapure filter was assembled within a bamboo cylinder (24 cm length, 6 cm diameter) through sequential layering of filtration media from bottom to top, following gravity-driven flow design principles. The assembly sequence, from the water outlet end upward, was as follows: (1) polishing cloth layer (6 layers, base); (2) gravel (155 g); (3) fine sand (100 g); (4) carbonized banana peel (20 g); (5) activated charcoal (20 g); (6) coconut shell fiber (15 g); and (7) sponge pre-filter (1.2 g, inlet end). Each layer was compacted gently to ensure uniform media distribution without excessive compression that would impede flow. The assembled filter was pre-washed with 500 mL of clean water prior to experimental trials to remove loose particles and condition the biosorbent surfaces.

2.4 Filtration Performance Evaluation

Contaminated water samples (250 mL) were prepared by collecting turbid surface water with visible suspended solids, muddy odor, and measured initial pH of 5.6. Each sample was gently stirred to ensure homogeneous particle distribution before being poured into the Banapure filter inlet. Performance parameters measured before and after filtration included: (1) water color and transparency (visual assessment under natural light); (2) odor (sensory evaluation); (3) turbidity (visual particle density assessment); (4) pH (digital pH meter); (5) output volume (graduated beaker measurement); and (6) filtration time (stopwatch). Each trial was conducted in triplicate to ensure reproducibility of results, and mean values are reported.

3. RESULTS AND DISCUSSION

3.1 Filtration Performance

The Banapure ecofilter demonstrated consistent and significant improvements across all measured water quality parameters. Table 2 summarizes the comparative performance data before and after filtration.

Table 2. Water Quality Parameters Before and After Banapure Filtration

Parameter	Before Filtration	After Filtration (Banapure)	Observation / Notes
Color	Brownish and turbid	Clear and transparent	Visual improvement confirmed under natural sunlight
Odor	Muddy, earthy smell	No detectable odor	Odor effectively adsorbed by activated charcoal layer
Turbidity	High (dense suspended particles)	Low (near negligible)	Sponge, coconut fiber, and sand layers collectively trapped particulates
pH	5.6 (mildly acidic)	7.2 (near neutral)	pH neutralized by gravel buffering; within WHO potable water range (6.5–8.5)
Volume (mL)	250 mL (input)	240–245 mL (output)	Minor volume loss (~2–4%) attributed to media absorption
Filtration Time	—	~7 seconds per 250 mL	Smooth, stable, and consistent water flow rate observed

Raw water input was characterized by pronounced turbidity (numerous suspended particles), a distinctly muddy odor, brownish-yellow coloration, and a mildly acidic pH of 5.6. Following passage through the complete Banapure filtration system, the output water was visually transparent and colorless, odor-free, and exhibited a near-neutral pH of 7.2—within the World Health Organization's recommended pH range for potable water (6.5–8.5). The output volume of 240–245 mL from a 250 mL input represents a volumetric recovery rate of 96–98%, indicating minimal absorption losses within the filter media. A filtration time of approximately 7 seconds per 250 mL confirms a smooth, practical, and field-applicable flow rate.

The pH increase from 5.6 to 7.2 is primarily attributed to the buffering capacity of the gravel layer, which likely contains calcium and magnesium carbonate mineral constituents that neutralize acidic ions in the water column. This passive pH correction is particularly advantageous in survival contexts where acidic surface water—common in tropical peat-dominated catchments—is the only available source.

3.2 Mechanism of Banana Peel Biosorption

The banana peel biosorbent layer constitutes the primary differentiating element of the Banapure system relative to conventional charcoal-sand filters. The surface of banana peel tissue contains a high density of active functional groups, including carboxyl (–COOH), hydroxyl (–OH), and amine ($–NH_2$) moieties [2]. Under aqueous conditions, these functional groups undergo proton dissociation to acquire negative surface charges, thereby enabling electrostatic attraction and coordination bond formation with positively charged heavy metal cations. Divalent metal ions documented to be effectively adsorbed by banana peel biosorbent include Lead (Pb^{2+}), Cadmium (Cd^{2+}), Copper (Cu^{2+}), and Zinc (Zn^{2+}), which are prevalent pollutants in industrial and agricultural runoff contaminating surface water sources [2].

In addition to metal ion removal, the naturally porous microstructure of carbonized banana peel facilitates the adsorption of dissolved organic compounds—including synthetic dyes, phenolic compounds, and aromatic species—through hydrophobic interactions, van der Waals forces, and π–π stacking mechanisms [8]. The combined biosorption and physical entrapment capacity of the banana peel layer thus provides a multi-modal contaminant removal mechanism not achievable by charcoal or sand alone.

3.3 Comparative Analysis: Banapure versus Commercial Portable Filters

Table 3 presents a structured comparative assessment of the Banapure ecofilter against commercially available portable pump and funnel filters, including products marketed under survival and outdoor recreation categories.

Table 3. Comparative Analysis of Banapure Ecofilter and Commercial Portable Filters

Aspect	Banapure (Banana Peel Ecofilter)	Commercial Portable Pump/Funnel Filters
Primary Material	Bamboo housing + natural media (banana peel, coconut fiber, activated charcoal, sand, gravel, cloth)	Plastic/silicone housing + multi-stage cartridges (carbon, ceramic, hollow fiber membrane)
Biodegradability / Environmental Impact	High — mostly biodegradable; locally sourced; no toxic waste	Low–Medium — cartridges disposable; housings reusable but non-biodegradable
Approximate Cost	Very low (local/DIY materials; < USD 2)	Medium–High (~USD 30–150 depending on kit)
Portability	Moderate — compact bamboo design; heavier than straw-type filters	High — backpackable; lighter cartridge-based designs available
Ease of Use	Simple pour-through operation; requires initial media pre-washing	Moderate — pump or squeeze operation; setup may be required
Filtration Performance	Effective turbidity, odor, and organic/heavy metal reduction; pathogen removal not guaranteed without post-treatment	Superior overall; removes bacteria and protozoa; advanced models eliminate viruses

Aspect	Banapure (Banana Peel Ecofilter)	Commercial Portable Pump/Funnel Filters
Best Use Case	Rural/low-resource field use; emergency short-term supply; educational settings; eco-conscious applications	Wilderness camping; group use; base-camp water supply
Maintenance & Lifespan	Replaceable biodegradable media; requires periodic drying/cleaning; shorter media lifespan	Replaceable cartridges; some cleaning required; longer functional lifespan
Regulatory Certification	None by default (requires laboratory testing for compliance)	Many models certified depending on brand and target market
Unique Advantage	Zero-waste design; uses agricultural by-product; minimal cost; strong circular economy narrative	Versatile for varied water sources; higher microbial removal capability

The comparative analysis reveals that Banapure offers a compelling and distinctive value proposition in the low-resource and emergency filtration segment. Its primary advantages—zero-waste material sourcing, negligible production cost, complete biodegradability, and passive operation without mechanical components—position it as a uniquely appropriate tool for rural communities, field researchers, disaster response teams, and environmentally conscious outdoor practitioners. By constructing the filter housing from bamboo rather than plastic, Banapure eliminates the microplastic leaching risk inherent in conventional commercial filter housings, an increasingly recognized contamination concern in water treatment [1].

The principal limitation of Banapure relative to advanced commercial filters is the absence of validated microbial pathogen removal capability. Hollow-fiber membrane and ceramic element-based commercial filters can eliminate bacteria, protozoa, and—in advanced models—viruses, which represent the primary biological contamination risk in untreated surface water. The Banapure system, in its current configuration, is not designed for microbial inactivation and should therefore be supplemented with post-filtration chemical disinfection (e.g., sodium hypochlorite at 0.1 mg/L) or solar disinfection (SODIS) protocols when used for drinking purposes in pathogen-risk environments. This limitation is acknowledged as a priority area for future development.

From a circular economy perspective, Banapure's design philosophy strongly aligns with the principles of organic waste valorization. Banana peel constitutes a high-volume agricultural by-product—globally, over 114 million metric tons of bananas are produced annually—of which the peel represents approximately 40% of total fruit mass [2]. The conversion of this waste stream into a functional water treatment material represents a meaningful contribution to sustainable resource utilization.

4. CONCLUSIONS

This study demonstrated that the Banapure portable ecofilter—a gravity-driven, multi-stage water purification system utilizing carbonized banana peel as the primary biosorbent—effectively improves key water quality parameters of contaminated surface water under controlled experimental conditions. Specifically, the following conclusions are drawn:

(1) Filtration Performance: Banapure successfully transformed turbid, odorous, and mildly acidic water (pH 5.6) into clear, odorless, near-neutral water (pH 7.2) within a rapid filtration time of approximately 7 seconds per 250 mL, with a volumetric recovery rate of 96–98%. All measured physical and chemical parameters showed marked improvement, consistent with the functional mechanisms of each filtration layer.

(2) Biosorbent Mechanism: The carbonized banana peel layer functions as an effective multi-modal biosorbent, leveraging carboxyl, hydroxyl, and amine surface functional groups to adsorb divalent heavy metal cations (Pb^{2+}, Cd^{2+}, Cu^{2+}, Zn^{2+}) and dissolved organic compounds through coordination bonding, hydrophobic interactions, and π–π stacking mechanisms.

(3) Comparative Advantage: Relative to commercial portable pump filters, Banapure offers superior environmental sustainability, negligible cost, complete biodegradability, and compatibility with a zero-waste

circular economy framework, while acknowledging its current limitation in validated microbial pathogen removal.

Future research should prioritize: (a) quantitative microbiological evaluation of Banapure's bacterial and protozoan removal efficiency; (b) standardized heavy metal removal testing using ICP-MS analysis; (c) optimization of banana peel carbonization parameters to maximize biosorbent surface area; and (d) scaling the device to higher-throughput configurations for community-level deployment in water-scarce regions.

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