Biochar and Moringa seed proteins for greywater treatment

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UNIVERSITY OF NAIROBI

Summary

This policy brief presents key findings and advice on the use of biochar and *Moringa oleifera* (MO) seed proteins for household greywater treatment. The research aimed to evaluate the effectiveness of a low-cost innovation for greywater treatment that addresses challenges regarding access to clean water, women's and children's water burdens and opportunities for recovering and reusing of greywater.

Initially, laboratory research was conducted to develop a protocol for using biochar and MO seed proteins in greywater treatment. The protocol was then applied to a local context of ten households (participants in a previous biochar projects) in rural Kenya to treat greywater generated from washing clothes.

Laboratory research demonstrated the effectiveness of the biochar-MO system in removing organic pollutants, heavy metals and improving water quality parameters. Field studies in Kenya further validated the approach, achieving significant reductions in turbidity, phosphates, nitrates, iron and surfactants. A sustainability assessment showed the system's alignment with circular bioeconomy principles, highlighting environmental benefits and opportunities for optimisation.

For this innovation to contribute to sustainable development, there is need for awareness raising, capacity building of local communities, government and technical experts, financial incentives, support for research and development, development of a context appropriate biochar MO greywater system, integration of circular bioeconomy principles and identification of appropriate disposal methods. Incorporation of community feedback and insights from an environmental sustainability assessment will ensure the long-term sustainability and scalability of the biochar-MO greywater treatment system.

Introduction

Fig. 1. Women carrying water from a river in Siaya, Kenya. Photo by Ivan Kozyatnyk.

Water scarcity is a pressing global issue that is exacerbated by a range of societal problems, e.g. population growth, climate change, urbanisation and industrial development. Climate change further compounds these challenges by altering precipitation patterns, increasing the frequency and severity of droughts and reducing water availability. The impacts of water scarcity are far-reaching and multifaceted. Food security is directly threatened because agriculture is heavily dependent on water availability. Therefore, water scarcity leads to lower crop yields and increased food prices. Health is compromised as inadequate water supplies hinder hygiene and sanitation practices, leading to the spread of waterborne diseases. Women and children's wellbeing is impaired, and education is affected because children, particularly girls, may have to spend a significant portion of their day collecting water, reducing their time and energy for school (Fig. 1). Socio-economic activities are also disrupted as industries and households struggle to meet their water needs, leading to economic losses and exacerbating poverty in vulnerable communities. This aim of this work was to conduct science-based participatory development of affordable and locally appropriate nature-based solutions for greywater treatment in developing countries.

Initial work was conducted at the Laboratory of Occupational and Environmental Medicine, Linköping, Sweden to develop procedures for using biochar and MO seed proteins in greywater treatment (Stage 1). The method was subsequently adapted for field research and training of farmers in ten households in the Kwale and Siaya Counties in Kenya (Stage 2). The ten households had all gained experience in producing biochar as a byproduct of cooking with a gasifier stove in an earlier biochar project. Stage 3 of the project involved sustainability assessment based on life cycle thinking and circular bioeconomy principles.

Why are low-cost greywater treatment solutions needed?

Innovations in low-cost greywater treatment could help alleviate water scarcity, food insecurity and women and children's water burden. Greywater comprises wastewater from kitchens, bathrooms and laundries and accounts for about 60% of the outflow from homes (Madungwe and Sakuringwa, 2007). As this water contains fewer pathogens and 90% less nitrogen than toilet wastewater, it requires a different treatment process. In addition, many contaminants may be present in greywater, e.g. pharmaceutical and personal care products, pesticides, surfactants, artificial sweeteners, etc., which may be difficult to manage. This greywater often pollutes drinking water sources. The characteristics of greywater are influenced by the environment as well as practice. Therefore, it is important to develop technologies that are context appropriate.

Biochar for water treatment

Tackling water scarcity requires the leveraging of locally available resources and affordable methods. Biochar is produced by heating and charring biomass from inexpensive local crops (e.g. oil palm, coconut shells, sugarcane bagasse and wood) at elevated temperatures in low oxygen conditions. While biochar can adsorb pollutants, its efficiency is sometimes limited by low porosity, reducing its ability to treat high concentrations of contaminants. The challenge ahead is to enhance its functionality and maximise its potential.

Moringa oleifera seed proteins for water treatment

Moringa oleifera (MO) is a tree species native to parts of Asia, Africa, South America and Pacific and Caribbean islands. Its seeds contain soluble proteins with antimicrobial and flocculating properties. However, a potential drawback is some of the MO seed proteins may remain in the water after treatment. This problem could be solved by combining MO with carbon materials such as biochar (Fig. 2).

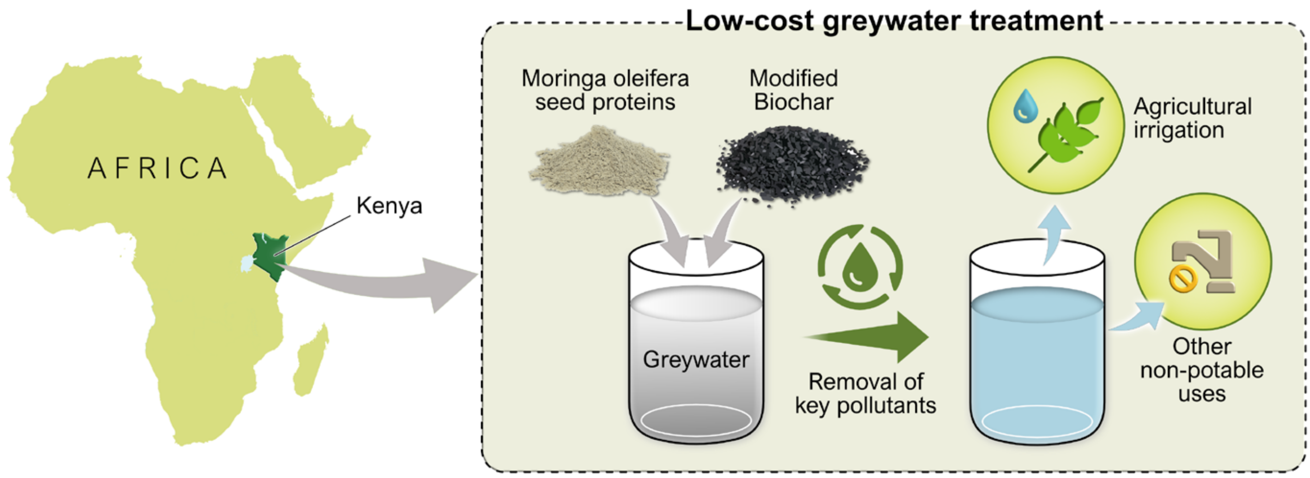

Fig. 2. Layout of the biochar-MO greywater treatment system.

Project goals

Our primary aim was to a develop a low-cost, nature-based method for greywater treatment by utilizing biochar sorbents made from locally available crop and woody residues combined with MO seed proteins in a single water treatment system. There were three pillar stages in our project.

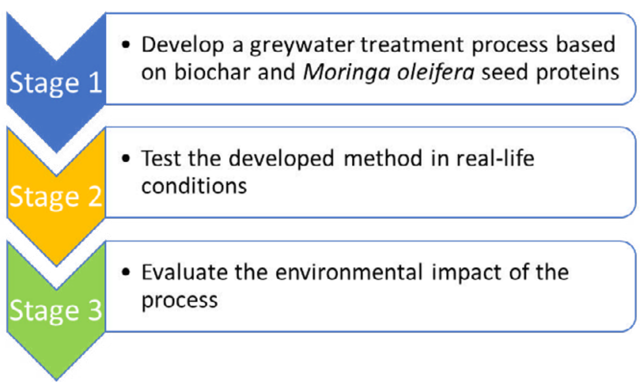

Fig. 3. The three stages of the water treatment project.

Project approach

Biochar was produced as a byproduct of cooking using local feedstocks, e.g. Eucalyptus and Markhamia firewood, in a Top-Lit UpDraft (TLUD) gasifier cookstove branded as "GASTOV". This cookstove is locally made by the Kenya Industrial Research and Development Institute (KIRDI) and is one of the cleaner cooking solutions being promoted in the country (Gitau et al., 2019). Following pyrolysis, the biochar was cooled and stored by the farmers for reuse, representing an integrated circular bioeconomy at a small-scale farm level. The biochar was ground and sieved before use to obtain a homogeneous powder (Fig. 4A) and maintain a consistent particle size of less than 0.15 mm across all samples, ensuring a uniform adsorption capacity.

MO seed powder was mixed with salt solution to extract the proteins (Fig. 4B). The resulting filtrate constituted the MO seed protein extract used in the subsequent greywater treatment.

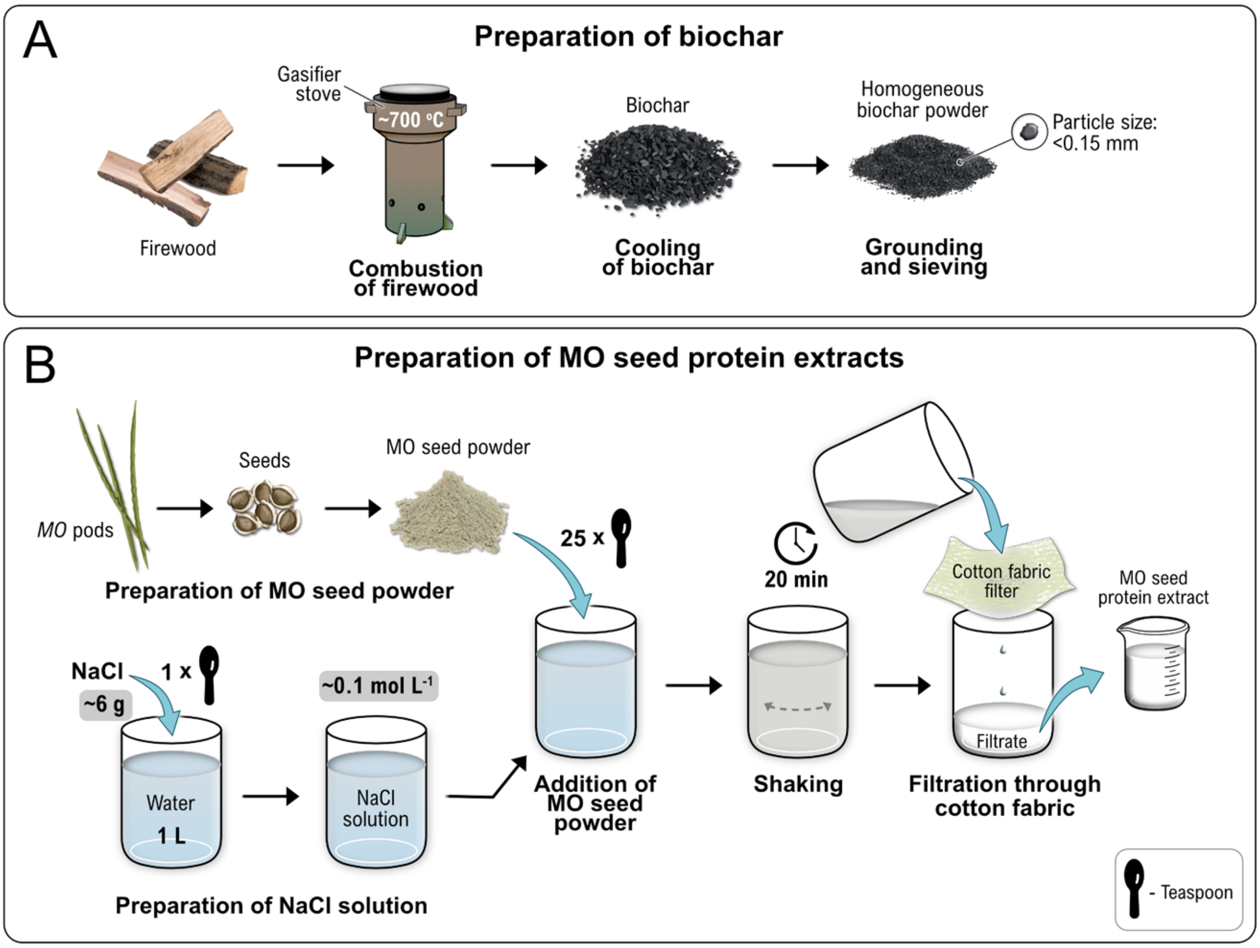

Fig. 4. Preparation of biochar (A) and MO seed protein filtrate (B).

Laboratory studies to develop a protocol for biochar-MO greywater treatment

The primary objective of work conducted at the Laboratory of Occupational and Medicine, Linköping, Sweden was to assess the effectiveness of biochar combined with MO seed proteins in treating greywater and develop a protocol for subsequent fieldwork. The laboratory work focused on removing organic contaminants (caffeine, chloramphenicol, trimethoprim, carbamazepine, diclofenac and bisphenol A) and heavy metals (Cr(VI), As(III), Co(II), Ni(II), Cu(II), Zn(II) and Pb(II)), and changing total dissolved solids (TDS), pH, colour and turbidity to ensure comprehensive evaluation of the water quality after treatment (Kozyatnyk and Njenga, 2023).

The order of application of biochar and MO coagulant was found to affect organic compound removal, with initial application of the coagulant followed by biochar being the most effective approach. Combined use of biochar and coagulant increased the removal of heavy metals but impeded the removal of organic pollutants.

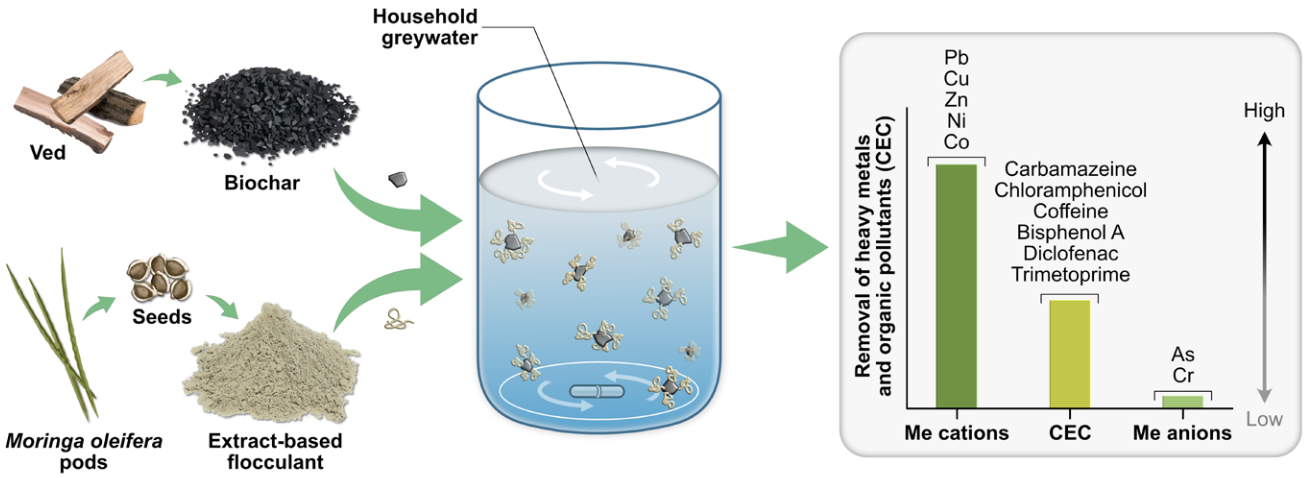

Fig. 5. Laboratory studies on biochar-MO greywater treatment.

The laboratory study also revealed that natural organic matter, clay and surfactants in household greywater challenged the coagulation process, inhibiting pollutant removal. Increasing the MO seed protein extract dose enhanced the water quality and contaminant removal. Thus, the dosage of MO-based coagulant needs to be adjusted depending on the organic matter characteristics of greywater.

Collaboration with farmers on the biochar-MO greywater treatment system

Study site and greywater collection

This part of the work involved testing and adapting the approaches developed in the laboratory to real-life conditions. A field study was conducted in June-July 2022 in the Kwale and Siaya Counties in Kenya. These areas had been included in a previous biochar project and represented typical socio-economic and environmental conditions. Kwale County is located along the coast and experiences higher humidity and rainfall than the inland Siaya County, which has drier conditions. The households selected for this work had all participated in the previous study to produce biochar using a gasifier cookstove. Five households were selected in each area with the help of research assistants that had worked with the farmers and research team in the earlier biochar project.

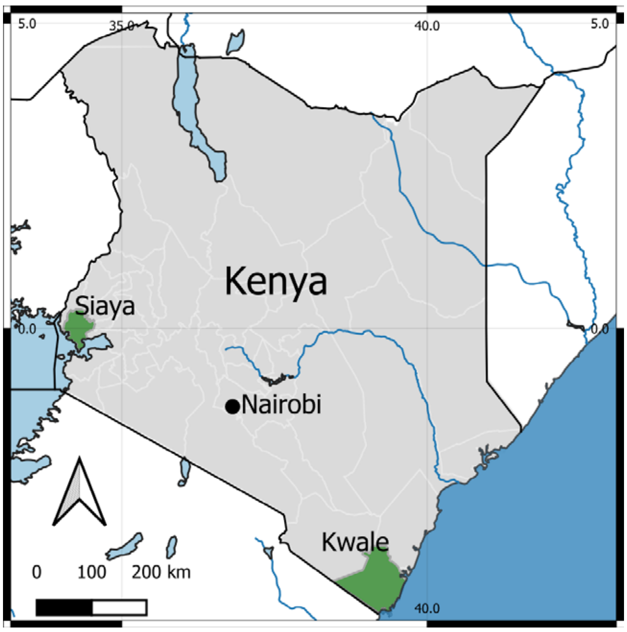

Fig. 6. Field study areas in Kenya.

Fig. 7. Hand washing clothes and resultant greywater in Kwale, Kenya. Photo by Ivan Kozyatnyk.

Greywater samples were collected from households following routine hand washing laundry practices to capture authentic variations in greywater characteristics (Fig. 7). Households were asked to use approximately 6 L of water and 30 g of washing powder or a bar soap for each washing cycle, with variations reflecting personal preferences and local practices. Greywater was sampled immediately after the washing process to ensure consistency.

Methods applied for greywater treatment in the field

The collected greywater was subjected to two treatment methods: (1) batch stirring, and (2) filtration, each leveraging the synergistic potential of biochar and MO seed protein extract (see Ndinda et al., 2024 for details).

Steps in batch **stirring method** (Fig. 8A). *(i) Biochar preparation and mixing with greywater:* Biochar was ground and sieved to attain particles of about 0.15 mm. 3 g of biochar powder was added to 0.5 litres of greywater and stirred for 20 minutes to allow adsorption of contaminants. *(ii) Preparation of MO seed filtrate:* MO seeds were peeled and ground into a powder. Twenty-five teaspoons (approximately 65 g) of MO seed powder were mixed with 1 litre of clean water and about 6 g of salt to prepare the MO filtrate. The MO filtrate was passed through a piece of clean cloth to obtain the extract, *(iii) Biochar-MO greywater treatment:* 25 ml of MO extract from step ii was added to 0.5 litres of greywater mixed with biochar from step i. The solution was stirred rapidly for 5 minutes and then slowly for 20 minutes to facilitate flocculation. After settling for 30 minutes, the supernatant was decanted and filtered through cotton fabric.

Steps in **filtration method** (Fig. 8B). *(i)* 50 ml of MO seed extract was added to 1 litre of greywater, which was then filtered through a makeshift filter. The filter comprised a 2 cm layer of cotton wool at the bottom, followed by 3 cm of sand, 6 cm of biochar and another 2 cm of sand. The filtration process removed the resulting flocs and remaining contaminants.

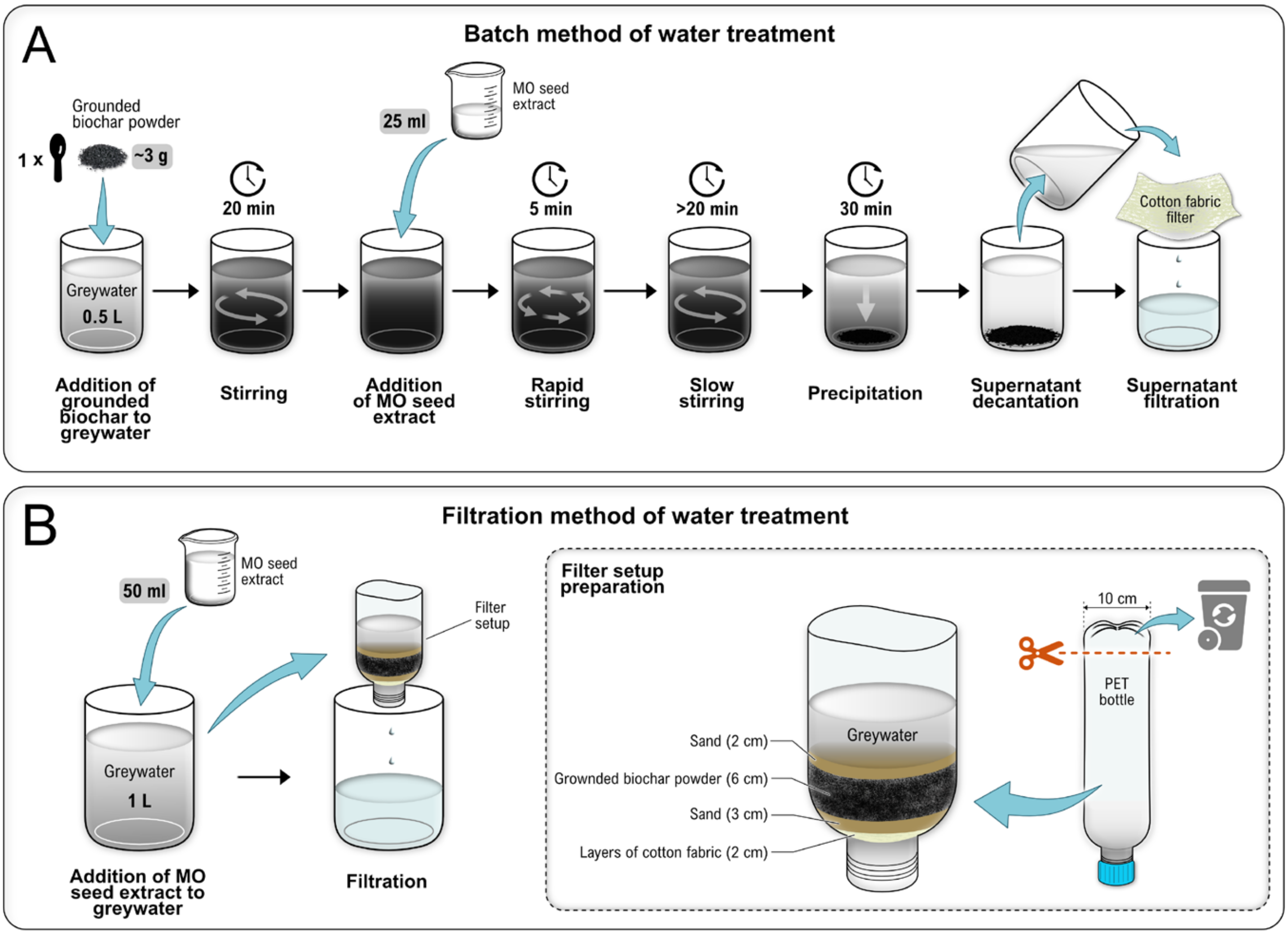

Fig. 8. Processes in (A) batch and (B) filtration methods.

The effectiveness of the greywater treatment was evaluated using a series of on-site and laboratory analyses. Portable analytical equipment was used for immediate field analysis (Fig. 9). Key parameters such as colour, turbidity, pH, TDS, nitrates, phosphates, total organic carbon (TOC) and iron were measured. Comprehensive chemical analyses were conducted at the Soils Laboratory, Department of Land Resource Management and Agricultural Technology (LARMAT), University of Nairobi.

Findings from biochar-moringa greywater treatment application

The field study demonstrated significant reductions in colour, turbidity (up to 90%), phosphates (up to 85%), nitrates (up to 75%), iron (up to 80%) and surfactants (up to 90%) in greywater treated with biochar and MO seed extract. Local water characteristics, such as pH, initial pollutant load and the presence of natural organic matter, influenced the treatment outcome. Households using different detergents and soaps produced greywater with varying pollutant profiles. Field studies showed the need for tailoring the treatment processes to specific local conditions, as the type of detergent affected the greywater's pollutant load and subsequent treatment efficiency.

Co-learning engagement on biochar-MO greywater treatment system

Community-researcher engagement was undertaken to discuss the processes and benefits of the biochar-MO greywater treatment system. During training, farmers described how they used the gasifier cookstove and produced biochar as a byproduct and its storage. The research team outlined the procedures for the preparation of biochar and MO powder and extract and steps in the filtration process using the two methods (batch or filtration) (Ndinda et al., 2024). The farmers took part in a hands-on demonstration of the procedures and suggested ways of using improvised equipment, such as old 20 litre water cans, in developing home-based filters, which could promote uptake and local ownership of the technology. The benefits discussed with farmers included the potential for recovering the treated greywater for irrigation and domestic purposes, such as washing house floors and clothes. It was emphasised to farmers that they could not use the treated greywater for drinking or watering livestock, even if it appeared clean, as it contained residual pollutants. Future research should aim to optimise treatment methods for scalability and integration of safe reuse practices, involving community input to ensure practicality and adoption.

Fig. 9. Quality assessment of treated greywater in Kwale County, Kenya. Photo by Mary Njenga.

Environmental sustainability of biochar-moringa greywater treatment system

The qualitative environmental sustainability assessment of the biochar-MO greywater treatment system was based on a life cycle approach and highlighted significant emission reductions and resource efficiency. The system can reduce the environmental burden associated with traditional greywater disposal methods by capturing and immobilizing contaminants, thus preventing their release into the ecosystem. The use of renewable resources and by-products in the treatment process aligns with circular bioeconomy principles, maximizing resource efficiency and minimising waste generation. Carbon storage in biochar could contribute to climate change mitigation if the promoted clean biochar production methods are used and the filter material is not burned after use.

The assessment provided insights into the remaining technical challenges and potential solutions. For instance, the disposal of spent filter material presents a significant hurdle. The study identified several disposal options, including co-disposal with faecal sludge in pit latrines, co-composting with organic farm residues or livestock manure and use in anaerobic digesters, each with its own set of benefits and challenges. Addressing these disposal issues is crucial to ensure the system's sustainability and environmental impact mitigation.

The biochar-MO seed extract based greywater treatment system offers notable potential environmental benefits, particularly through water reuse for irrigation and other domestic purposes, except drinking. The approach not only conserves freshwater resources but also reduces the burden on women and children, who are often responsible for fetching water. By treating greywater and making it suitable for irrigation, the system enhances local water sustainability and contributes to food security and income generation in rural communities. Furthermore, use of locally available materials, such as biochar and MO seed extract, promotes the environmental sustainability of water treatment technologies. The treatment system aligned well with circular bioeconomy principles by promoting the efficient use of local biomass, minimising waste and enhancing recycling of nutrients.

Policy recommendations

- There is need for awareness raising and capacity development on the procedures in the context-based biochar-MO seed protein greywater treatment system. This should include the environmental and social-economic benefits.
- Community feedback and reflective co-learning with technical experts are essential for enhancing adoption, adaptation and adjustment to a local context and response to user needs and preferences.
- To increase adoption, services such as financial incentives through subsidies or grants to small-scale farmers could enhance water reuse, hence reducing pressure on freshwater sources.
- Further research is needed to improve the treatment process and address potential limitations, e.g. by focusing on the removal of specific contaminants and optimizing the dosage and application methods. Pilot projects and field trials are important for scaling, adoption and adaptation to local cost and sustainability assessments.
- It is necessary to involve the private sector in local production units and leverage locally available resources for economic development and job creation in rural areas.
- It would be useful to integrate circular bioeconomy principles that promote the use of locally available resources, waste minimisation, resource efficiency, recycling and reuse of treated greywater, and appropriate disposal and reuse of spent filter materials.
- Prevention of secondary pollution requires establishing guidelines for the safe disposal or reuse of spent filter materials while providing climate change mitigation through carbon storage in biochar.

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This brief was prepared by **Ivan Kozyatnyk** (Occupational and Environmental Medicine, Region Östergötland, Sweden); **Cecilia Sundberg** (The Swedish University of Agricultural Sciences, Uppsala, Sweden), **Catherine Ndinda** and **Mary Njenga** (Center for International Forestry Research and World Agroforestry [CIFOR-ICRAF], Nairobi, Kenya).

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More information

Video on field trip experience:

https://youtu.be/stIwAeKls1E

https://youtu.be/B5QIZ2iQomk

Contacts

Ivan Kozyatnyk, Occupational and Environmental Medicine, Region Östergötland, Linköping, Sweden, (ivan.kozyatnyk@regionostergotland.se, ivan.kozyatnyk@liu.se)

Cecilia Sundberg, Department of Energy and Technology and Department of Soil and Environment and Department of Ecology and Management, The Swedish University of Agricultural Sciences (cecilia.sundberg@slu.se)

Mary Njenga, Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF), Nairobi, Kenya (m.njenga@cifor-icraf.org)

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