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Performance and Durability of a Gravity Charcoal Filter for Organic Pollution

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Abstract: Confronting the health emergency posed by the organic pollution of Lake Kabongo for the city of Kolwezi, this study proposes a frugal and circular innovation: a gravity filter designed on the principle of resource economy and the use of local materials. The objective is threefold: performance, optimization, and durability to address the polluting load (TOC and COD > 12 mg/L) affecting a population of over 600,000 people. The filter, structured around accessible media (gravel, sand, artisanal activated carbon from coconut shells and lemon juice), was subjected to a rigorous experimental design testing six different layer assemblies. The data reveal optimal performance for a three-layer architecture (5/50/35 cm), achieving a reduction of approximately 52% in COD and TOC parameters. Turbidity decreased from 20.8 to 6.6 NTU, bringing it closer to the WHO standard, without significant pH fluctuation. Beyond efficiency, a multicriteria analysis (Pivot Table and Radar Chart) demonstrated that this configuration offers the best balance between purification efficiency and resilience, minimizing clogging risks. More than just a treatment process, this filter embodies a socio-technical solution rooted in its local context, offering a sustainable, economical, and ecological alternative for securing access to safe water.

Keywords: *Artisanal Activated Carbon, Gravity Filtration, Organic Pollution, Optimization, Drinking Water, Lake Kabongo.*

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I. INTRODUCTION

In the Lualaba province of the Democratic Republic of Congo, a concerning public health reality is unfolding due to the lack of access to safe drinking water. Only one in two inhabitants has reliable access to quality water in Kolwezi, a city with a population of nearly 600,000 [10]. Yet, this region is abundant in water resources, including Lake Kabongo.

Unfortunately, this lake is subject to various forms of pollution: domestic wastewater, residues from artisanal mineral processing, agricultural runoff, not to mention the concerning proximity of an open-pit mine operated by the company COMMUS [11]. This forced coexistence results in an alarming organic load, where TOC and COD levels regularly exceed concentrations of 12 mg/L, figures that sound like a verdict: this water is unfit for consumption and is therefore poisonous for anyone who drinks it without treatment [22].

This reality justifies the imperative development of alternative, low-cost treatment solutions using local and easily reproducible resources [14].

This work aligns with this dynamic aim of improving the quality of heavily polluted surface water by exploring the performance of a domestic gravity filter. The innovation lies in the use of artisanal activated carbon, produced from coconut shells – an agricultural waste product collected for reuse – and chemically activated with lemon juice, a natural, low-cost, and accessible activating agent in Kolwezi [29, 1].

This study aims to answer the following question: How can the configuration of a gravity filter with artisanal activated carbon be optimized to effectively and sustainably reduce the organic load of the water from Lake Kabongo?

➢ *The Specific Objectives are:*

- To evaluate the filter's effectiveness in reducing COD, TOC, and turbidity [18, 16].

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- To determine the optimal configuration of the filter layers (gravel, sand, carbon) via an experimental design [23, 2].
- To analyze the system's durability by assessing the risks of media clogging and saturation [19, 21].

➢ *Methodological Approach:*

A laboratory testing campaign was conducted to test six distinct filter bed configurations. The main physicochemical parameters – COD, TOC, turbidity, pH, and TDS – were measured before and after filtration, in accordance with standardized protocols [3]. However, the study has certain limitations, notably the absence of direct measurement of the carbon's adsorption capacity and some flow rate variations that could not be fully controlled [24, 20].

II. MATERIALS AND METHODS

➢ *Study Site and Materials*

Lake Kabongo (10°43′41.7″S, 25°28′33.8″E), located in the peri-urban area of Kolwezi, is the recipient of multiple pollution sources [11]. Three local, abundant, and low-cost materials were selected to constitute the filter bed:

- Gravel (3-4 mm): Serving as a drainage layer and mechanical support at the base of the filter.
- River Sand (0.5-1.5 mm): Ensuring the mechanical filtration of suspended solids [2].
- Artisanal Activated Carbon (1-2 mm): Produced by calcining coconut shells, followed by chemical activation with lemon juice to develop its microporosity and increase its adsorption capacity [1, 29].

Fig 1 Photographs of the Three Filter Media (Gravel, Sand, Activated Carbon)

➢ *Experimental Setup and Experimental*

The gravity filter consisted of a 1.20 m high PVC column (110 mm diameter), providing a useful filtration height of 90 cm. Its operation, purely gravity-fed, required no external energy, following the proven principle of slow sand filters [2].

A total of six configurations were tested this way, allowing the exploration of interactions between the media to determine the optimum.

An experimental design was followed to study the effect of sand layer thickness (levels: 30 to 55 cm) and carbon layer thickness (levels: 30 to 55 cm), with a constant gravel layer (5 cm) [16, 23].

Fig 2 Diagram of the Gravity Filter Showing the Layered Media

➢ *Analytical Protocol*

For each test, a volume of 20 L of raw water collected from the lake was filtered through a column filled with the local media. Filtrate samples were collected at regular time intervals (T_0, T_{15}, T_{30}, T_{45}, T_{60} min). Before each test, backwashing with clean water was performed to avoid errors related to residual saturation or clogging from a previous test [19], thus allowing precise identification of the specific effect of each configuration. Calibration was performed before each analysis series using certified reagents and according to recommended protocols [3, 4]. The water quality parameters were then measured using the following portable devices [3, 4, 18]:

Fig 3 Photograph of the Measurement Devices Used

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(Turbidity: AZOVTES AE86065 Turbidimeter (0,01 à 1000 NTU); pH: Pen-type pH meter (0–14; précision ±0,01 à ±0,1; 10–40 °C); TDS (0– 10000 ppm; précision ±2 %) and Conductivity: Multiparameter pen tester; COD and TOC: Multiparameter pen tester (précision 0,1))

Treatment efficiency was quantified by the reduction rate (%) calculated as follows: Evaluation criterion:

η (%) = $100 \times (C_i - C_p) / C_i$ (1)

where C_i and C_p represent the initial and final concentrations of the measured parameter, respectively [18].

III. RESULTS AND DISCUSSION

➢ *Performance Summary and Identification of the Optimal Configuration*

Table 1 consolidates the performance data for each configuration, serving as the basis for a pivot table analysis.

Table 1 Performance summary for multicriteria analysis

Configuration (G-S-C)	Flow Rate (L/3min)	Parameter	Initial Value	Minimum Value	Final Value	% Reduction (Final)
5-50-35	2	COD (mg/L)	12.5	5.96	5.96	52.3%
		TOC (mg/L)	17.8	8.51	8.51	52.2%
		Turbidity (NTU)	20.8	6.64	6.64	68.1%
5-40-45	2	COD (mg/L)	11.9	6.20	6.20	47.9%
		TOC (mg/L)	17.0	8.86	8.86	47.9%
		Turbidity (NTU)	24.6	8.04	13.20	46.3%
5-55-30	1	COD (mg/L)	7.40	7.04	7.04	4.9%
		TOC (mg/L)	10.6	10.06	10.06	5.1%
		Turbidity (NTU)	45.9	5.70	5.70	87.6%

(Note: G-S-C = Gravel-Sand-Charcoal layer thickness in cm; COD = Chemical Oxygen Demand; TOC = Total Organic Carbon)

The superiority of the 5-50-35 configuration was demonstrated by a remarkable reduction of over 52% in organic parameters [16, 23] This performance stems from a strategic design: the sand layer, of sufficient thickness, ensures optimal mechanical pre-filtration that preserves the integrity of the downstream activated carbon. Simultaneously, the charcoal layer, calibrated at 35 cm, guarantees an optimal contact time with pollutants, thereby maximizing adsorption capacity.

Table 2 Sand-Charcoal Interaction Matrix (Average COD/TOC Reduction Rate %)

Charcoal Thickness (cm) → Sand Thickness (cm) ↓	30	35	40	45	50	55
30						15,6%
35					24,4%	
40				18,7%		
45			18,7%			
50		52,3%				
55	4,4%					

Note: The matrix shows the combined average reduction percentage for COD and TOC for each thickness combination. Empty cells indicate configurations not tested.

➢ *Durability Analysis*

Durability was assessed by monitoring the evolution of performance over time. A significant increase in turbidity at the end of the cycle indicates clogging of the filter bed, while an increase in COD/TOC signals the saturation of the carbon's adsorption capacity [21, 19].

This synergy between the media creates the perfect balance between physical protection and chemical efficiency [18, 1].

➢ *Sand/Charcoal Interaction and Optimization via Square Matrix*

Table 2 (square matrix) visualizes the critical interaction between sand and charcoal thickness. It highlights the necessary compromise: an excess of sand reduces the space dedicated to adsorption, while an excess of charcoal, without sufficient prior mechanical filtration, leads to accelerated clogging [23, 19].

The cell 5-50-35 (50 cm sand, 35 cm charcoal) presents the highest value, confirming its status as the optimal equilibrium point.

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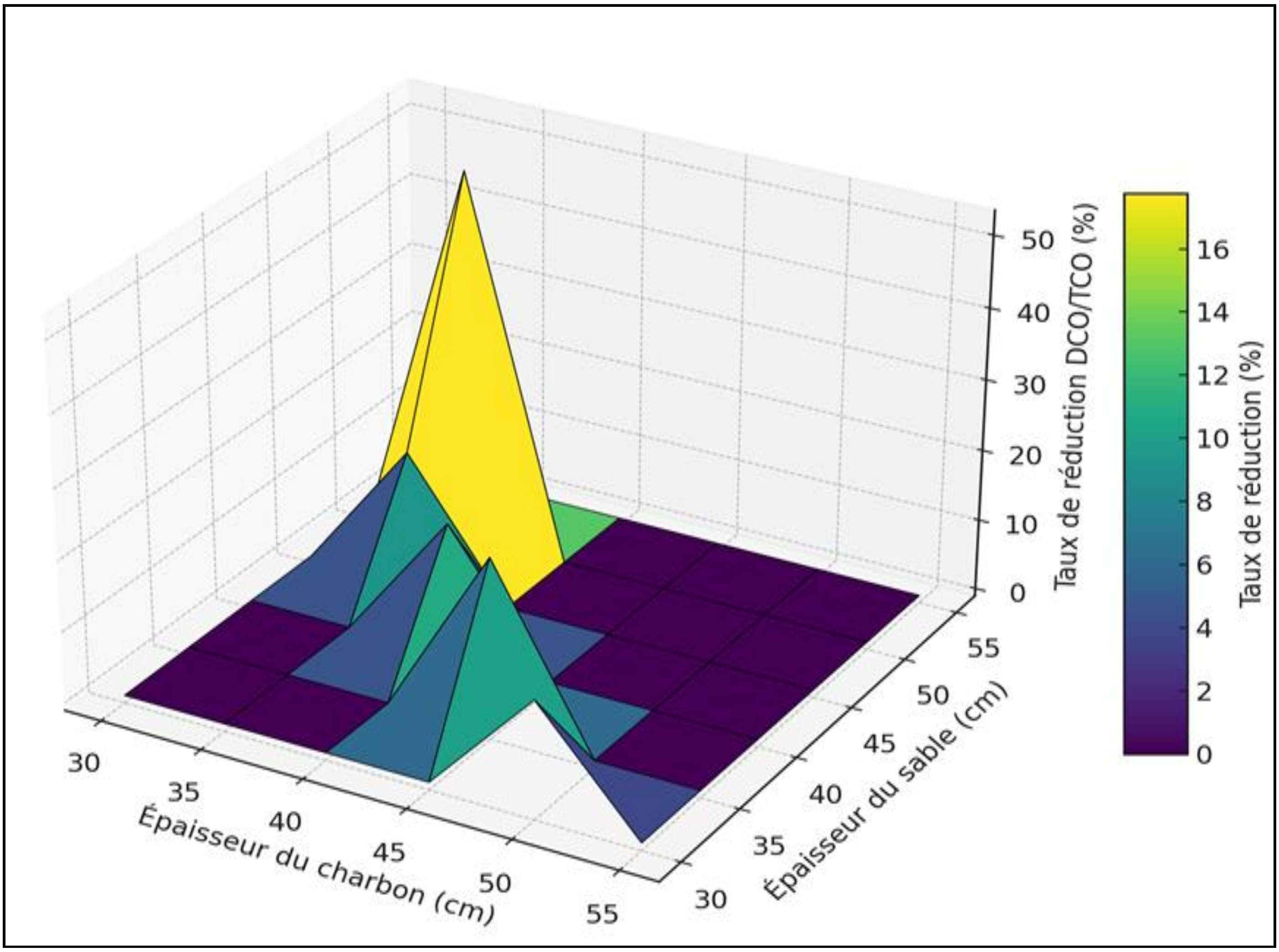

Fig 4 3D Response Surface: Sand/Charcoal Interaction

(*This contour curve illustrates the response surface of the sand/charcoal interaction, based on the matrix from Table 2.*)

➢ *Multicriteria Analysis via Radar Chart*

To visually compare overall performances, a radar chart (Figure 5) compares three key configurations against four simultaneous criteria.

Table 3 Clogging and Saturation Analysis

Configur.	**Turbidity Initial (NTU)**	**Turbidity Min.**	**Turbidity Final**	**Clogging Index (Turbidity)**	**DCO Final (mg/L)**	**DCO Min. (mg/L)**	**Saturation Index (DCO)**	**TCO Final (mg/L)**	**TCO Min. (mg/L)**	**Saturation Index (TCO)**
5-55-30	45.9	5.70	5.70	Stable	7.04	7.04	Stable	10.1	10.1	Stable
5-50-35	20.8	6.64	6.64	Stable	5.96	5.96	Stable	8.51	8.51	Stable
5-45-40	33.4	9.94	11.23	Low	5.37	5.37	Stable	7.67	7.67	Stable
5-40-45	24.6	8.04	13.20	High	7.44	7.16	Low	10.6	10.2	Low
5-35-50	104.4	10.35	15.28	Moderate	7.37	6.33	High	10.5	9.05	High
5-30-55	84.2	19.04	20.90	Low	8.47	7.33	High	12.1	10.5	High

- *Legend for Indices :*

✓ Stable: Final Value = Minimum Value. Constant performance.

✓ Low: Slight degradation between the minimum and final value.

✓ Moderate: Notable degradation.

✓ High: Strong degradation, indicating rapid clogging or saturation that limits the duration of effective use.

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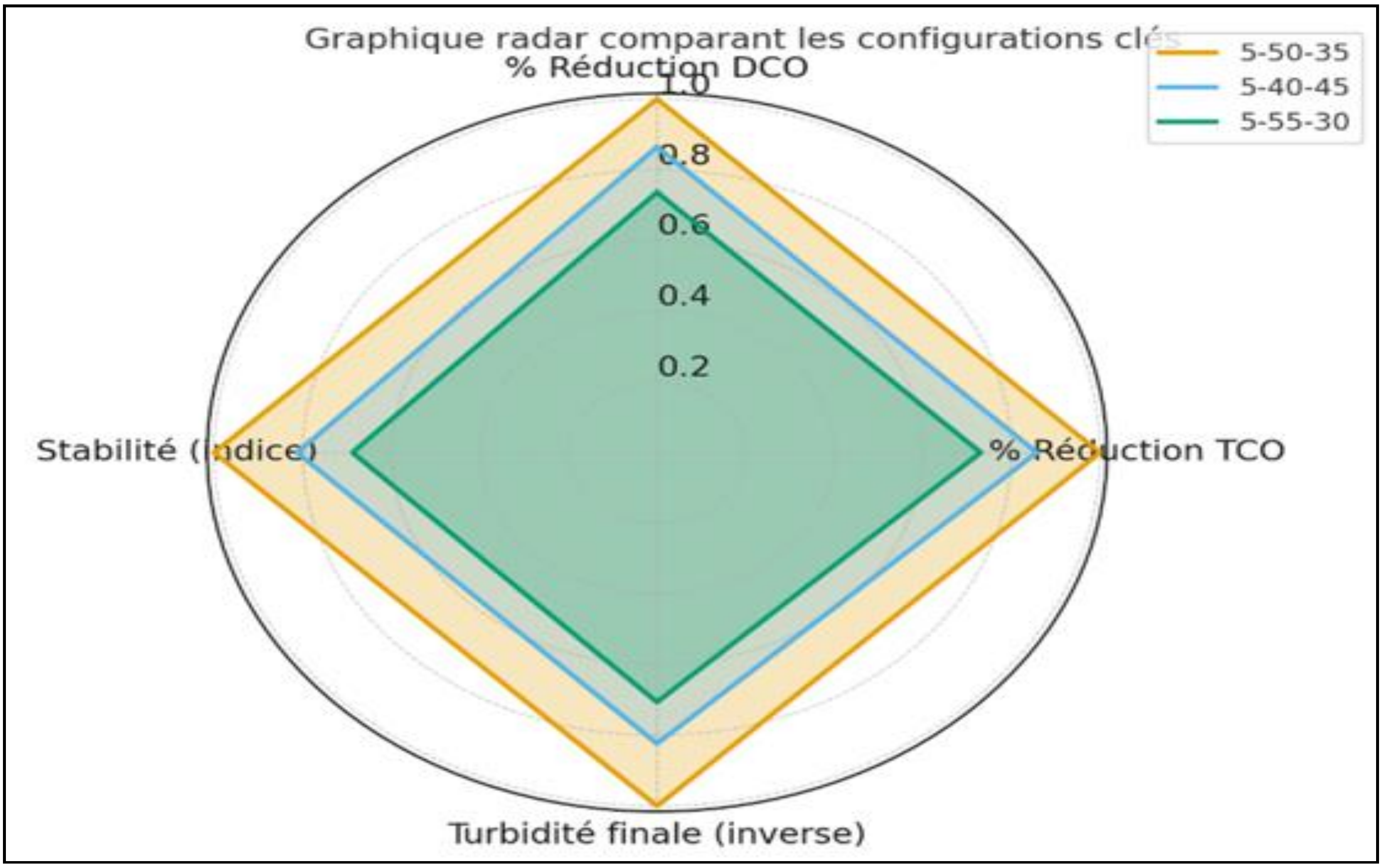

Fig 5 Comparative Radar Chart of Key Configurations

- *Legend:*

✓ Axis 1 : % COD Reduction (Maximization)
✓ Axis 2 : % TOC Reduction (Maximization)
✓ Axis 3 : Final Turbidity (Minimization)
✓ Axis 4: Filtration Flow Rate (Optimization)

The 5-50-35 configuration plots the widest and most balanced area, demonstrating its superiority not in just one criterion, but across all performance metrics, thereby validating the choice as the optimal configuration.

➢ *Durability Analysis: Clogging and Saturation*

Table 3 evaluates the stability of performance over time, a key indicator of durability and required maintenance frequency.

which show early signs of clogging or saturation, the 5-50-35 configuration demonstrates remarkable stability [21].

This operational robustness grants it a significantly longer effective service life, ensuring reliable and durable treatment performance over time [16, 24].

IV. CONCLUSION

This study evaluated the efficiency and durability of a multilayer gravity filter using local materials to reduce the organic load of water from Lake Kabongo, characterized by initial COD and TOC concentrations exceeding 12 mg/L. Six filtration configurations, varying the thickness of river sand (35 to 55 cm) and artisanal coconut shell activated carbon (30 to 55 cm), with a constant gravel layer of 5 cm, were tested at two flow rates (1 and 2 L/3 min).

Results indicate that the 5-50-35 configuration (5 cm gravel, 50 cm sand, 35 cm carbon) exhibits the best performance, with an average reduction of 52.3 % in COD, 52.2 % in TOC, and 68.1 % in turbidity. This efficiency is attributed to the optimal balance between mechanical filtration provided by the sand and chemical adsorption achieved by the activated carbon, ensuring sufficient contact time for the removal of organic pollutants.

Durability analysis shows that this configuration maintains stable performance over multiple filtration cycles, without significant clogging or saturation, in contrast to other configurations exhibiting moderate to high clogging or saturation indices. These findings confirm that the combined use of sand and artisanal activated carbon allows for an effective, durable, and economically accessible domestic gravity filtration system, suitable for the peri-urban context of Kolwezi.

Further studies on the specific adsorption capacity of the carbon, saturation kinetics, and large-scale evaluations could optimize the design further and ensure sustainable community-scale application. This approach demonstrates the relevance of locally sourced, sustainable, and low-cost solutions for the treatment of heavily polluted surface waters.

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Bavon NDALA Mbavu

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APPENDIX

➢ *Table 4 Summary of Performance by Configuration (for Pivot Table Analysis)*

This table consolidates the key data from each trial for comparative analysis and easy filtering.

Table 4 Performance Summary for Multicriteria Analysis

Configuration (G-S-C cm)	Débit (L/3min)	Paramètre	Valeur Initiale	Valeur Minimale Atteinte	Valeur Finale	Moyenne (Filtrée)	% Réduction (Finale)
5-55-30	1	Turbidité (NTU)	45,9	5,70	5,70	8,66	87,6%
		DCO (mg/L)	7,40	7,04	7,04	8,17	4,9%
		TCO (mg/L)	10,5	10,1	10,1	11,68	3,8%
5-50-35	2	Turbidité (NTU)	20,8	6,64	6,64	7,30	68,1%
		DCO (mg/L)	12,5	5,96	5,96	6,59	52,3%
		TCO (mg/L)	17,8	8,51	8,51	9,39	52,2%
5-45-40	2	Turbidité (NTU)	33,4	9,94	11,23	10,54	66,4%
		DCO (mg/L)	6,60	5,37	5,37	5,58	18,6%
		TCO (mg/L)	9,45	7,67	7,67	7,97	18,8%
5-40-45	2	Turbidité (NTU)	24,6	8,04	13,20	9,52	46,3%
		DCO (mg/L)	7,61	7,16	7,44	7,30	2,2%
		TCO (mg/L)	10,9	10,2	10,6	10,40	2,8%
5-35-50	2	Turbidité (NTU)	104,4	10,35	15,28	15,09	85,4%
		DCO (mg/L)	9,72	6,33	7,37	7,21	24,2%
		TCO (mg/L)	13,9	9,05	10,5	10,29	24,5%
5-30-55	2	Turbidité (NTU)	84,2	19,04	20,90	20,00	75,2%
		DCO (mg/L)	10,0	7,33	8,47	8,14	15,3%
		TCO (mg/L)	14,4	10,5	12,1	11,63	16,0%