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Abstract

Access to safe drinking water remains a major challenge in many developing nations, necessitating the development of low-cost and efficient point-of-use filtration systems. This study optimized clay–coconut shell composite water filters using Grey Relational Analysis (GRA) to obtain the optimal parametric settings for water filtration characteristics. The characteristics evaluated include flow rate (FR) and total coliform removal (TC) efficiency while the parameters included weight of the filter (w), composition (C), and firing temperature (T). An orthogonal array experimental design was adopted to minimize the number of experiments while capturing parameter interactions. The higher-the-better GRA approach was employed to determine the best parametric setting across multiple performance characteristics simultaneously. Results show optimal grey parametric setting was $T_3C_3W_1$ which can be translated as the temperature at 900 °C, composition at 60:10:30 and a weight at 39.09 g. Also, the influence of temperature on flow rate ($GRG_i(FR, T)$) is 0.5349, while the influence of composition ($GRG_i(FR, C)$) is 0.5373 and influence of weight ($GRG_i(FR, W)$) is 0.5313. Composition has the strongest effect on flow rate. In the same wise, influence of temperature on percent total coliform removal is ($GRG_i(TC, T)$) is 0.6031, while the influence of composition ($GRG_i(TC, C)$) is 0.5916 and influence of weight ($GRG_i(TC, W)$) is 0.6826. Weight has the strongest effect on total coliform removal. The study demonstrates that Grey Relational Analysis is an effective tool for multi-objective optimization of composite ceramic filters and supports the development of low-cost household water treatment systems.

Keywords: Ceramic filter; Clay; Grey Relational Analysis; Water purification; Multi-Response optimization

1. Introduction

One of the most important long-term objectives when it comes to water intervention is to provide safe and high-quality water services required to promote a healthy living environment and other health benefits for people. According to the United Nations, availability of a decentralized and sustainable portable drinking water source is essential to achieving SDG target 6.1, which aims to "provide universal and equitable access to safe and affordable drinking water for all by the year 2030" [1]. The regional data by UNICEF in 2025 revealed that one out of every 4 persons globally, still lacked access to a safe source of drinking water which is the same as reported in 2021 [2]. This indicates that over 2 billion people are still not able to conveniently access drinkable water and water intervention strategies has yielded little to no results. Eight out of ten individuals who lack access to a basic drinking water supply reside in rural areas and sub-Saharan Africa, and one out of every four of these people does not have access to source of water purification for the purpose of drinking [3].

A significant barrier to the supply of clean drinking water sources is the availability of a dependable and efficient technology that can assist in removing fecal contamination. Farrow et al. [4] explicated that while the installation of modern drinking water sources, such as community tap water or in-house pipe water, has the qualities of a desirable, long-term safe drinking water source, setting them up and maintaining them is difficult and non-parsimonious, particularly in rural areas where there is lack infrastructures to access the water. In the use community tap water, contamination is typically introduced during the transportation process as reviewed by the study of Wright et al. [5].

Due to a lack of amenities, water treatment can be costly and sometimes impossible especially for those in the rural areas [6]. Ceramic water filters has shown promising results in combatting the seemingly unyielding water issues coupled with its endorsement by WHO for use in purifying water for drinking in homes [7]. It can be produced using materials that are locally

sourced, readily available and of low cost as presented in the study of Adeyinka-Aderanti et al., [8] where the materials used were clay, coconut shell, and activated carbon that was made from a mixture of carbonized coconut shell and lime water.

From the trends in literature, the use of clay-based materials effectively removes contaminants from drinking water, consequently lowering the incidence of diarrhea in developing nations [9]. Solomon et al. [10] reported a reduction in the fluoride level, turbidity and total dissolved solids of ground water using their clay based filters. Another study [11] revealed the ability of clay based ceramic filters to efficiently remove *E. Coli.*, Total coliform, dissolved solids and other substances like Nitrates from Lagos Lagoon.

The ceramic filter is influence by various production parameters like the firing temperature, filter blend, composition, and many others. Firing temperature and processing techniques influences biofilm formation on ceramic filters, which in turn affects the filter performance [12]. As the firing temperature rises, the porosity of ceramic filters decreases [9]. This reduction in porosity is as a result of change in the mineralogy of the clay with increasing temperature. Findings from Zereffa & Bekalo's [13], revealed that the porosity of filters rises as the percentage of burnout material added to the filter composition increases (high porosity suggests greater pores that will allow the easy passage of water). Bulta and Michael's [9] investigation reported a flow rate of 150 mL/h at porosity of 53.06%, while the flow rate was increased to 350 mL/h when the porosity increases to 63.91%. The flow-rate, porosity, strength, and microbial removal effectiveness of a filter are all impacted by the size and amount of carbonaceous material. Zereffa and Bekalo [13] observed a decrease in grain size with increasing firing temperature and concluded that this could be the cause of the variation in flow rate and microorganism removal effectiveness between filters fired at 900 °C, 950 °C, and 1000 °C. A rise in firing temperature causes a rise in flow rate. According to Ajibade et al. [14], the elimination of coliform and *E. coli* increases from 12% for a clay to sawdust ratio of 30:70 to

100% for clay to sawdust ratio of 90:10. Bulta and Michael [9], found that the microbial removal efficiency of ceramic filters increased with an increase in the percentage composition of clay and firing temperature, corroborated this. Ceramic filters with less porosity are more effective at eliminating microorganisms.

Having established the ability of ceramic filters to provide drinkable water for households, it is worthy of note that there is a divergence of opinion on the most appropriate parametric settings (filter composition, firing temperature, weight, filter materials, shape of filters), from different authors, hence the need for the deployment of scientific tools such as Taguchi, and grey Relational analysis to determine the parametric settings required to obtain optimal filter performance before production of these filters are carried out.

GRA is a process optimisation technique. It is used to determine the best input parameter values for different characteristics that is being considered as the output of a process [15].

Characteristics could be based on higher the better or lower the better performance requirement.

A review on process optimization for machining was carried out by Chakraborty et al. [15], the review concluded that GRA was the most effective tool as the process of computation was straightforward and free from unrealistic criteria or assumptions. A study used GRA with combined compromise solution to obtain the best parametric setting for carbon fiber-reinforced plastic (CFRP) machining during wet drilling and concluded on the effectiveness of the tool in positively identifying the parameters to give optimal settings [16]. A study carried out in 2020 predicted the ideal input parameters for various quality attributes for the milling process of a steel sample using GRA and Taguchi [17] and another study used these techniques to determine optimal parameters in sheet forming for steel [18].

Most literature have used GRA for optimising engineering and scientific processes but there is paucity of data on the use of GRA for obtaining the optimal parametric settings to obtain the desirable characteristics of a clay-based filter for water purification. This study therefore has

the objective of; (1) determining the optimal parametric settings for the production of ceramic filters for water purification and (2) evaluating the most influential parameter in the filter characteristics of consideration. Instead of carrying out various experiments to compare the variations in the flowrate, and contaminant removal ability of ceramic filters produced using different composition blends and firing temperature, this study explicitly indicates the specific blends, firing temperature and weight that will produce optimal water and filter characteristics.

2. Optimization Methodology

The materials considered in this study for the production of water filters are clay, coconut shell, and activated carbon. Composition, firing Temperature (700 °C, 800 °C, 900 °C, and 1000 °C), and weight of the filter are the parametric settings while the quality characteristics addressed are flow rate (FR) and percentage Total *coliform* removal (TC).

Grey Relational Analysis

The first step is normalisation. Normalisation process is used to treat the different values of divergent data and bring it within the same range. It is a means of contrasting the specific comparison sequences with the primary sequences. The normalization of data in GRA is carried out in line with the desired quality characteristic.

When the least value of a primary sequence is desired, it is regarded as “lower-the-better” quality characteristic which is normalized using Equation (1)

$$\alpha_i^*(TC) = \frac{\max \alpha_i^{(0)}(TC) - \alpha_i^{(0)}(TC)}{\max \alpha_i^{(0)}(TC) - \min \alpha_i^{(0)}(TC)} \quad (1)$$

When the highest possible value of a primary sequence is desired, it is regarded as “higher-the-better” quality characteristics which is normalized using equation 2.

$$\alpha_i^*(TC) = \frac{\alpha_i^{(0)}(TC) - \min \alpha_i^{(0)}(TC)}{\max \alpha_i^{(0)}(TC) - \min \alpha_i^{(0)}(TC)} \quad (2)$$

It there is set target to be achieved, the primary sequence is normalized by dividing the primary sequence by the first value of the sequence (Equation 3)

$$\alpha_i^*(TC) = \frac{\alpha_i^{(0)}(TC)}{\alpha^{(0)}(TC)} \quad (3)$$

Where $\alpha_i^{(0)}(TC)$ is the primary sequence, Total Coliform removal, $\alpha_i^*(TC)$ is the sequence after normalization, $\max \alpha_i^{(0)}(TC)$ is the largest value of $\alpha_i^{(0)}(TC)$ while $\min \alpha_i^{(0)}(TC)$ is the least value of $\alpha_i^{(0)}(TC)$.

Grey relation coefficient and grey relational grade

Where $\Delta_i^*(TC)$ is the sequence of difference of the primary sequence $\alpha_i^{(0)}(TC)$ and secondary sequence $\alpha_i^*(TC)$ i.e. (Equation 4)

$$\Delta_i^*(TC) = |1 - \alpha_i^*(TC)| \quad (4)$$

$$\varepsilon_i(TC) = \frac{\min \Delta_i(TC) + \phi(\max \Delta_i(TC))}{\Delta_i^*(TC) + \phi(\max \Delta_i(TC))} \quad (5)$$

ϕ is given as 0.5, it is a distinguishing effect used to adjust the range of the of comparative environment and the differences of the relational coefficients. $\min \Delta_i$ is the minimum value of $\Delta_i(TC)$, $\max \Delta_i(TC)$ is the maximum value of $\Delta_i(TC)$

The grey relational grade is calculated as the average sum of the grey relational coefficients which is obtained in equation 6 using equation as follows

$$GRG_i(FR, TC) = \left(\frac{1}{n}\right) \sum_i^n \varepsilon_i(FR, TC) \quad (6)$$

The degree of association between the primary and secondary sequences is thus indicated by the grey relational grade. The degree to which the secondary impact affects the original sequence is likewise indicated by the grey relational grade. In particular, a secondary sequence's grey relational grade will be higher than other secondary sequences' if it has greater influence over the primary sequence than other secondary sequences. Consequently, the overall

value of the differences between data sequences and the evaluated correlation between sequences are assessed by gray relational analysis.

Experimental design

The output (response) variables are the flow rate and Total coliform. Minitab 16, a commercially available statistical software package was used to design the experiment. As a result, sixteen experimental trials based on the Taguchi method $L_{16}(3)^4$ orthogonal array was used. The problem in this investigation is a three factor four level optimisation problem (Table 1). Table 1 is a result of experimental data from the study of Adeyinka-Aderanti et al. [11]. Although, an experimental data is not a requirement for this optimization process as an orthogonal array was used to represent the intended values as in Table 2 following the Taguchi orthogonal array design. The right orthogonal array must be selected in order to disperse all of the factor level combinations; hence, $L_{16}(3)^4$ is the orthogonal array that is suited for this investigation (Table 2).

Table 1 The primary and secondary sequences for Flow rates and Total Coliform

Experimental trial	Secondary sequence			Primary sequence	
	Temperature (T) (°C)	Composition (C)	Weight (w) (g)	Flow rate (FR)	Total Coli (TC)
1	700	60:30:10	39.09	0.17	95.64
2	700	60:20:20	38.91	1.41	97.54
3	700	60:10:30	38.84	2.25	98
4	700	60:00:40	38.66	2.14	97.18
5	800	60:30:10	38.91	0.26	95.18
6	800	60:20:20	39.09	1.89	96.18
7	800	60:10:30	38.66	2.41	95.27
8	800	60:00:40	38.84	2.2	91.91
9	900	60:30:10	38.84	0.3	96.18
10	900	60:20:20	38.66	2.02	95.55
11	900	60:10:30	39.09	2.83	98.18
12	900	60:00:40	38.91	2.77	99
13	1000	60:30:10	38.66	0.35	91.36
14	1000	60:20:20	38.84	2.48	89
15	1000	60:10:30	38.91	2.92	86.73
16	1000	60:00:40	39.09	2.37	88

Table 2 Orthogonal array for the experimental trials

Experimental Trial	Temperature	Composition	Weight
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

Experimental results were normalized using higher-the-better criteria (Equation 2) for Flow rate and percentage total coliform removal.

Results and Discussion

In this work, the primary sequences (characteristics) are flow rate and Total coliform removal while the secondary sequences (Parametric settings) are, Temperature, composition, and weight were as represented in Table 2. The experimental factors contain three factors and four levels as shown in the Table 2 to develop 16 experimental trials.

The higher, the flow rates, and Total coliform, the better the purity and quality of the water from the water treatment filter. Therefore, the “higher-the-better” quality characteristic is desired. Equation 2 was used to normalize the data. Table 2 shows the data concerning the orthogonal array L_{16} for the experimental trials. The flow rates and Total coliform were fixed as primary sequences $\alpha_i^{(0)}(TC), i = 1 \text{ to } 16, (\text{Note: } TC \text{ can be replaced with } FR)$. The sequences obtained from the normalization of data with the use of equation (2) are shown in the first and second column of Table 3 with values ranging from 0 to 1.

The difference sequence was obtained using equation 4 by performing the same operation at $i = 1 - 16$, outcome of all Δ_{0i} for $i = 1$ to 16 is shown Table 3, column 3 and 4. The difference sequences values were obtained by subtracting the normalized sequence values from 1.

The distinguishing effect is substituted into Equation 5 to calculate the grey relational coefficient. For parameters of the same local ϕ is 0.5. Tables 3 (Column 4, 5 and 6) show the grey relational coefficient and grey grade for all sixteen comparison sequences. In this investigation, the Taguchi method's response table was used to derive the average grey relational grade for each factor level combination for the four columns in the orthogonal array and finding their means. For example, in the first column in Table 4 which represents sintering temperature (T), Trials 1, 2, 3, 4 are the experimental trials for factor T when it is described as level 1. Thus, the grey relational grade for T_1 is the average grey relational grades obtained at the aforementioned experimental trails. The iteration was executed for every factor-level combination as shown in the orthogonal array in Table 2.

Table 3 Grey relational analysis of the primary sequence

$\alpha_i^*(FR)$	$\alpha_i^*(TC)$	Δ_{0iFR}	Δ_{0iTC}	Grey coef FR	Grey coef TC	Grey Grade
0	0.7261	1.0000	0.2739	0.7142	0.646	0.6801
0.4509	0.881	0.5491	0.119	0.4765	0.8077	0.6421
0.7563	0.9185	0.2437	0.0815	0.6723	0.8598	0.76605
0.7163	0.8516	0.2837	0.1484	0.6379	0.7711	0.7045
0.0327	0.6886	0.9673	0.3114	0.3407	0.6162	0.47845
0.6254	0.7701	0.3746	0.2299	0.5716	0.685	0.6283
0.8145	0.696	0.1855	0.304	0.7293	0.6218	0.67555
0.7381	0.4221	0.2619	0.5779	0.6562	0.4638	0.56
0.0472	0.7701	0.9528	0.2299	0.3441	0.685	0.51455
0.6727	0.7188	0.3273	0.2812	0.6043	0.64	0.62215
0.9672	0.9331	0.0328	0.0669	0.9384	0.8819	0.91015
0.9454	1	0.0546	0	0.9015	1	0.95075
0.0654	0.3773	0.9346	0.6227	0.3485	0.4453	0.3969
0.84	0.185	0.1600	0.815	0.7575	0.3802	0.56885
1	0	0.0000	1	1	0.3333	0.66665
0.8	0.1035	0.2000	0.8965	0.7142	0.358	0.5361

$\alpha_i^*(FR)$ is sequence of normalised flow rate values; $\alpha_i^*(TC)$ is sequence of normalized Total Coliform removal value; Δ_{0iFR} is the sequence of difference of the Flow Rate; Δ_{0iTC} is the sequence of difference of the Total Coliform removal. Grey coef FR is the Grey Relational Coefficient of the Flow rate. Grey coef TC is the Grey Relational Coefficient of the Total Coliform removal.

As established by Fung, [19] and Ajibade *et al.*, [20] grey relational grade indicates the relationship between the primary sequence as well as the secondary sequence. The higher value of the primary sequence indicates that the secondary sequence has a strong correlation to the primary sequence. Thus, the secondary sequence with higher values of the grey grades would produce higher flow rates and total coliform. Using this principle, the optimal grey parametric setting from Table 4 was obtained as $T_3C_3W_1$ which can be translated as a temperature at 900 °C, composition at 60:10:30 and a weight at 39.09 g.

Table 4 Grey Response table for Grey Relational grade

Levels	T	C	W
1	0.6982	0.5175	0.6887
2	0.5856	0.6154	0.6845
3	0.7494	0.7546	0.5798
4	0.5421	0.6878	0.5998

Furthermore, the grey relational grades can be used to ascertain the parameter or factor exerting the highest influence on the Flow rates (Tables 6 to 8) and Total coliform (Tables 9 to 11). By setting the sixteen experimental trials flow rates and Total coliform as primary sequences, $\alpha_{flow}^{(0)}(FR)$ and $\alpha_{(t)}^{(0)}(TC)$, while the factor levels in the sixteen experimental trials are the secondary sequences $\alpha_T^{(0)}$, $\alpha_C^{(0)}$ and $\alpha_W^{(0)}$

Normalisation of the data was done using Equation 3 i.e. normalized by first value in the sequence to obtain Table 5. The difference sequence was obtained using the same method described in Equation 4.

Table 5 Sequences after normalization of primary and secondary sequence

Experimental trial	Secondary sequence			Primary sequence	
	Temperature °C	Composition	Weight (g)	Flow rate (FR)	Total Coli (TC)
1	1	1	1.0000	0	0.7261
2	1	2	0.9954	0.4509	0.881
3	1	3	0.9936	0.7563	0.9185
4	1	4	0.9890	0.7163	0.8516
5	1.142857	1	0.9954	0.0327	0.6886
6	1.142857	2	1.0000	0.6254	0.7701
7	1.142857	3	0.9890	0.8145	0.696
8	1.142857	4	0.9936	0.7381	0.4221
9	1.285714	1	0.9936	0.0472	0.7701
10	1.285714	2	0.9890	0.6727	0.7188
11	1.285714	3	1.0000	0.9672	0.9331
12	1.285714	4	0.9954	0.9454	1
13	1.428571	1	0.9890	0.0654	0.3773
14	1.428571	2	0.9936	0.84	0.185
15	1.428571	3	0.9954	1	0
16	1.428571	4	1.0000	0.8	0.1035

From Table 6 to 8, it can be gathered that the influence of temperature on flow rate (GRG_i (FR, T)) is 0.5349, while the influence of composition (GRG_i (FR,C)) is 0.5373 and influence of weight (GRG_i (FR,W)) is 0.5313. Composition has the strongest effect on flow rate.

From Table 9 to 11, it can be gathered that the influence of temperature on percent total coliform removal was (GRG_i (TC, T)) is 0.6031, while the influence of composition (GRG_i (TC,C)) is 0.5916 and influence of weight (GRG_i (TC,W)) is 0.6826. Weight has the strongest effect on total coliform removal.

239 **Table 6** Most influential factor for Flow rate; Sintering Temperature of filter

Temperature	Normalised	Δ_{0iFR}	Δ_{0iTC}	Grey Coeff
	1	0	0	1
700	1	7.294118	7.294118	0.5191
700	1	12.23529	12.23529	0.3916
700	1	11.58824	11.58824	0.4046
800	1.14285714	0.386555	0.386555	0.9532
800	1.14285714	9.97479	9.97479	0.4412
800	1.14285714	13.03361	13.0336	0.3766
800	1.14285714	11.79832	11.79832	0.4003
900	1.28571429	0.478992	0.478992	0.9427
900	1.28571429	10.59664	10.59664	0.4263
900	1.28571429	15.36134	15.36134	0.3389
900	1.28571429	15.0084	15.0084	0.3441
1000	1.42857143	0.630252	0.630252	0.9259
1000	1.42857143	13.15966	13.15966	0.3744
1000	1.42857143	15.7479	15.7479	0.3333
1000	1.42857143	12.51261	12.51261	0.3862
				0.5349

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241 **Table 7** Most influential factor for Flow rate; Composition of filter

Composition	Normalised	Δ_{0iFR}	Δ_{0iTC}	Grey Coeff
60:30:10	1	0.00000	0.00000	1
60:20:20	2	6.29412	6.29412	0.5297
60:10:30	3	10.23529	10.23529	0.4092
60:00:40	4	8.58824	8.58824	0.4522
60:30:10	1	0.52941	0.52941	0.9305
60:20:20	2	9.11765	9.11765	0.4374
60:10:30	3	11.17647	11.17647	0.3881
60:00:40	4	8.94118	8.94118	0.4422
60:30:10	1	0.76471	0.76471	0.9026
60:20:20	2	9.88235	9.88235	0.4177
60:10:30	3	13.64706	13.64706	0.3418
60:00:40	4	12.29412	12.29412	0.3657
60:30:10	1	1.05882	1.05882	0.87
60:20:20	2	12.58824	12.58824	0.3602
60:10:30	3	14.17647	14.17647	0.3333
60:00:40	4	9.94118	9.94118	0.4162
				0.5373

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243

244 **Table 8** Most influential factor for Flow rate; Weight of filter

Weight	Normalised	Δ_{0iFR}	Δ_{0iTC}	Grey Coeff
39.09	1.0000	0.0000	0.0000	1
38.91	0.9954	7.2987	7.2987	0.5257
38.84	0.9936	12.2417	12.2417	0.3979
38.66	0.9890	11.5992	11.5992	0.4109
38.91	0.9954	0.5340	0.5340	0.9381
39.09	1.0000	10.1176	10.1176	0.4443
38.66	0.9890	13.1875	13.1875	0.3802
38.84	0.9936	11.9476	11.9476	0.4038
38.84	0.9936	0.7711	0.7711	0.913
38.66	0.9890	10.8934	10.8934	0.4262
39.09	1.0000	15.6471	15.6471	0.3408
38.91	0.9954	15.2987	15.2987	0.3459
38.66	0.9890	1.0698	1.0698	0.8832
38.84	0.9936	13.5946	13.5946	0.3731
38.91	0.9954	16.1811	16.1811	0.3333
39.09	1.0000	12.9412	12.9412	0.3847
				0.5313

245

246 **Table 9** Most influential factor for Total Coliform; sintering Temperature of filter

Temperature	Normalised	Δ_{0iFR}	Δ_{0iTC}	Grey Coeff
700	1	0	0	1
700	1	0.019866	0.019866	0.9295
700	1	0.024676	0.024676	0.9138
700	1	0.016102	0.016102	0.9419
800	1.4285714	-0.14767	0.14767	0.6386
800	1.4285714	-0.13721	0.13721	0.6553
800	1.4285714	-0.14673	0.14673	0.6401
800	1.4285714	-0.18186	0.18186	0.5893
900	1.28571429	-0.28007	0.28007	0.4823
900	1.28571429	-0.28666	0.28666	0.4765
900	1.28571429	-0.25916	0.25916	0.5017
900	1.28571429	-0.25058	0.25058	0.5101
1000	1.42857143	-0.47332	0.47332	0.3553
1000	1.42857143	-0.498	0.498	0.3438
1000	1.42857143	-0.52173	0.52173	0.3333
1000	1.42857143	-0.50845	-0.50845	0.3391
				0.603163

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248

249

250 **Table 10** Most influential factor for Total Coliform; Composition of filter

Composition	Normalised	Δ_{0iFR}	Δ_{0iTC}	Grey Coeff
60:30:10	1	0.00000	0.00000	1
60:20:20	2	-0.98013	0.98013	0.6111
60:10:30	3	-1.97532	1.97532	0.4381
60:00:40	4	-2.98390	2.98390	0.3404
60:30:10	1	-0.00481	0.00481	0.9969
60:20:20	2	-0.99435	0.99435	0.6077
60:10:30	3	-2.00387	2.00387	0.4346
60:00:40	4	-3.03900	3.03900	0.3363
60:30:10	1	0.00565	0.00565	0.9964
60:20:20	2	-1.00094	1.00094	0.6061
60:10:30	3	-1.97344	1.97344	0.4383
60:00:40	4	-2.96487	2.96487	0.3418
60:30:10	1	-0.04475	0.04475	0.9718
60:20:20	2	-1.06943	1.06943	0.5902
60:10:30	3	-2.09316	2.09316	0.4239
60:00:40	4	-3.07988	3.07988	0.3333
				0.59168125

251

252 **Table 11** Most influential factor for Total Coliform; Weight of filter

Weight	Normalised	Δ_{0iFR}	Δ_{0iTC}	Grey Coeff
39.09	1.0000	0.0000	0.0000	1.0000
38.91	0.9954	0.0245	0.0245	0.6439
38.84	0.9936	0.0311	0.0311	0.5875
38.66	0.9890	0.0271	0.0271	0.6204
38.91	0.9954	-0.0002	0.0002	0.9955
39.09	1.0000	0.0056	0.0056	0.8878
38.66	0.9890	0.0071	0.0071	0.8619
38.84	0.9936	-0.0326	0.0326	0.5761
38.84	0.9936	0.0120	0.0120	0.7869
38.66	0.9890	0.0101	0.0101	0.8143
39.09	1.0000	0.0266	0.0266	0.6248
38.91	0.9954	0.0397	0.0397	0.5274
38.66	0.9890	-0.0338	0.0338	0.5672
38.84	0.9936	-0.0630	0.0630	0.4129
38.91	0.9954	-0.0886	0.0886	0.3333
39.09	1.0000	-0.0799	0.0799	
				0.68266

253

254

Conclusion

The results demonstrated that the optimal grey parametric setting was $T_3C_3W_1$, corresponding to a firing temperature of 900 °C, a composition ratio of 60:10:30, and a filter weight of 39.09 g. This parameter combination produced the highest overall grey relational grade, indicating the most favourable compromise between water production capacity and microbiological treatment performance. The analysis further revealed that composition exerted the strongest influence on flow rate, while filter weight had the greatest influence on total coliform removal efficiency. These findings highlight the importance of considering multiple interacting parameters during filter design rather than relying on single-factor optimization approaches. Thereby addressing a major challenge in ceramic filter development, which is the identification of parameter combinations that provide a balance between flow performance and microbial removal efficiency.

Beyond identifying the optimal production conditions, this study contributes to the growing body of knowledge on low-cost household water treatment technologies by demonstrating the applicability of Grey Relational Analysis to ceramic water filter optimization. The use of locally sourced materials such as clay and coconut shell further supports the development of affordable and sustainable water treatment solutions suitable for rural and resource-constrained communities. The outcomes of this study therefore provide a scientific basis for improving ceramic filter production processes and advancing decentralized water treatment technologies capable of contributing to Sustainable Development Goal 6 on universal access to safe drinking water.

279 **List of Abbreviations**

280	C	Composition
281	FR	Flow Rate
282	GRA	Grey Relational Analysis
283	GRG	Grey Relational Grade
284	T	Temperature
285	TC	Total coliform removal
286	UN	United Nations
287	UNICEF	United Nations Children's Fund
288	w	Weight
289	WHO	World Health Organisation
290	Δ_{0iFR}	Delta sequence for Flow rate
291	Δ_{0iTC}	Delta sequence for Total coliform

292 **Declarations**

293 **Availability of Data Materials**

294 All data used shall be made available upon request.

295 **Competing Interests**

296 The authors declare no competing interests

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299 **Authors' contributions**

300 AD was part of the conceptualization, data collection, analysis of the data and also wrote the
301 manuscript. AA was also part of the conceptualization and reviewed the manuscript as a
302 supervisor. JO was part of the conceptualization of the method to use for optimization, guided
303 on how the process is carried out and reviewed the manuscript as a supervisor. GWA was a

contributor in the manuscript writing as a mentor. FO was part of the conceptualization and review of the manuscript as a supervisor. All authors read and approved the final manuscript.

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References

1. United Nations (2023) Goal 6: Ensure access to water and sanitation for all. UN Regional Information Center for Western Europe. <https://unric.org/en/sdg-6/>. Accessed 21 December, 2025.
2. UNICEF (2025) Fast facts: 1 in 4 people globally still lack access to safe drinking water – WHO, UNICEF. <https://www.unicef.org/press-releases/fast-facts-1-4-people-globally-still-lack-access-safe-drinking-water-who-unicef>. Accessed 20 May 2026.
3. WHO, UNICEF (2021) Progress on household drinking water, sanitation and hygiene 2000 –2020 Five years into the SDGs. Drinking Water UNICEF Data. Geneva: World Health Organization (WHO) and the United Nations Children’s Fund (UNICEF). <https://www.unwater.org/sites/default/files/app/uploads/2021/07/jmp-2021-wash-households-LAUNCH-VERSION.pdf>. Accessed 19 August 2023..
4. Farrow C, McBean E, Huang G, Yang AL, Wu YC, Liu Z, Dai ZN, Fu HY, Cawtel T, Li YP (2018) Ceramic Water Filters: A Point-of-Use Water Treatment Technology to remove Bacteria from Drinking Water in Longhai City, Fujian Province, China. J Envir Info 32(2):63-68.

- 328 5. Wright J, Gundry S, Conroy R (2004) Household drinking water in developing countries:
329 a systematic review of microbiological contamination between source and point-of-use.
330 Trop Med and Int. Health 9:106-117.
- 331 6. Ankidawa BA, Tope AA (2017) Design of slow sand filter technology for rural water
332 treatment in Girei, Adamawa State, North Eastern Nigeria. Asian J Envir Ecology 3(3):1.
- 333 7. Erhuanga E, Banda MM, Kiakubu D, Kashim IB, Ogunjobi B, Jurji Z, Ayoola I, Soboyejo
334 W (2021) Potential of ceramic and biosand water filters as low-cost point-of-use water
335 treatment options for household use in Nigeria. J Wat, San and Hyg for Dev 11(1):126-
336 140.
- 337 8. Adeyinka-Aderanti AD, Agbeleye AA, Agunbiade FO, Agunsoye JO (2025) Effect of
338 Process Parameters on the Properties of Clay-Based Composite Filter for Water
339 Purification. J of Eng Res 30:50-65.
- 340 9. Bulta AL, Micheal GAW (2019) Evaluation of the efficiency of ceramic filters for water
341 treatment in Kambata Tabaro zone, southern Ethiopia. Envir Sys Res 8(1).
- 342 10. Solomon A, Andoshea DM, Abebea AM, Terfasab TT, Ganesha T, Honec FG, Tegegnec
343 NA, Tesfamariam BB (2023) Optimization of preparation parameters of ceramic pot
344 water filters for potential application of microbial and fluoride removal from groundwater.
345 Heliyon, e13261.
- 346 11. Adeyinka-Aderanti AD, Agbeleye AA, Agunbiade FO, Agunsoye JO (2024) Efficiency of
347 ceramic composite filter produced using Nano particulate carbonaceous material. ABUAD
348 J Eng Res & Dev (AJERD) 7(2):446-454. <https://doi.org/10.53982/ajerd.2024.0702.XX-j>.
- 349 12. Shepard, Z.J., Zhang, Y., Anaya, N.M., Cardace, D., & Oyanedel-Craver, V. (2020).
350 Development of Ceramic Water Filter Clay Selection Criteria. Water 12:1657.
- 351 13. Zereffa EA, Bekalo TB (2017) Clay Ceramic Filter for Water Treatment. Mat Sci & App
352 Chem, 34:69–74.

14. Ajibade FO, Akosile SI, Oluwatuyi OE, Ajibade TF, Lasisi KH, Adewumi JR, Babatola JO, Oguntuase AM (2019) Bacteria removal efficiency data and properties of Nigerian clay used as a household ceramic water filter. *Results in Eng* 2:100011.
15. Chakraborty S, Datta HN, Chakraborty S (2023) Grey Relational Analysis-Based Optimization of Machining Processes: a Comprehensive Review. *Process Integr Optim Sustain* 7: 609–639. <https://doi.org/10.1007/s41660-023-00311-4>.
16. Shunmugesh K, Raphel A, Kurian S, Hiremath S, Anne G, Murthy BRN, Vishwanatha HM (2025) A novel way to optimize the process parameters by integrating the grey relational coefficient and the combined compromise solution for machining the CFRP composites. *Scientific Reports* 15(1):34729.
17. Lusi, N., Pamuji, D.R., Fiveriati, A., Afandi, A. and Prayogo, G.S., 2020, December. Application of Taguchi and grey relational analysis for parametric optimization of end milling process of ASSAB-XW 42. in *International Seminar of Science and Applied Technology (ISSAT 2020)* 198:514-517. Atlantis Press.
18. Ramkumar K, Varatharajulu M, Priya CB, Vijayan V (2023) Prediction of Optimal Input Parameters for Incremental Sheet Metal Forming Process with Taguchi-Based GRA and TOPSIS Technique Using AISI 316. *JOM* 75:3985–3995. <https://doi.org/10.1007/s11837-023-06011-1>
19. Fung CP (2004) Manufacturing Process Optimization for Wear Property of Fiber Reinforced Polybutylene Terephthalate Composites with Grey Relational Analysis. *Wear* 254:298-306. doi:10.1016/S0043-1648(03)00013-9.
20. Ajibade OA, Agunsoye JO, Oke SA (2018) Optimisation of wear parameters of dual filler epoxy composites using the Grey Relational Analysis. *ANNALS of Fac Eng Hunedoara – Int J of Eng* 16:123-142.