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Overall Performance of Specific Household Water Filtration Techniques on Turbid Water and Effects of Selected Factors

Aladekomo, J. O., Rotimi, T.M., Akinlade, S.A., Agunlejika, A.A., Amusan, E. A., Olaniyan, S.A., Zubair, M.B., Olawale J.A. Nasiru, K. M., Towobola, J.A., and Oke, I.A.

Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract

Turbid surface water remains an important household water source in many low-resource communities where piped drinking-water supplies are inadequate or unreliable. Household filtration techniques (HFTs), including fibre/cartridge, ceramic, activated-carbon, and bio-sand filters, can significantly improve water quality; however, their effectiveness depends strongly on operational conditions. This study evaluated selected HFTs—activated-carbon, ceramic, and fibre filters—for removing health-related water-quality parameters, including alkalinity, electrical conductivity, chromium, iron, pH, and mercury. The effects of settling/treatment time, alum/coagulant dose, raw-water turbidity, and number of filter units were evaluated using analysis of variance (ANOVA) and Taguchi techniques. Results demonstrated that raw-water turbidity, filter configuration, coagulant dose, and settling time significantly influenced treatment performance. For the activated-carbon filter, the highest overall performance (98.26%) was achieved using one filter unit, 1500 NTU turbidity, 120 mg/L alum, and 10 min settling time, whereas the lowest (67.57%) occurred with three units, 2000 NTU, 80 mg/L alum, and 15 min. The ceramic filter achieved a maximum performance of 97.29% using three units, 1500 NTU, 80 mg/L alum, and 5 min, while the minimum (77.46%) occurred using one unit, 500 NTU, 200 mg/L alum, and 5 min. Fibre filtration achieved maximum and minimum performances of 92.83% and 78.96%, respectively, under corresponding operating conditions of two units/1500 NTU/80 mg/L/10 min and one unit/1500 NTU/120 mg/L/10 min. The findings demonstrate that treatment efficiency is strongly condition-dependent. Reliable treatment of highly turbid water therefore requires a multi-barrier system integrating coagulation, sedimentation, particle filtration, adsorption, and final disinfection.

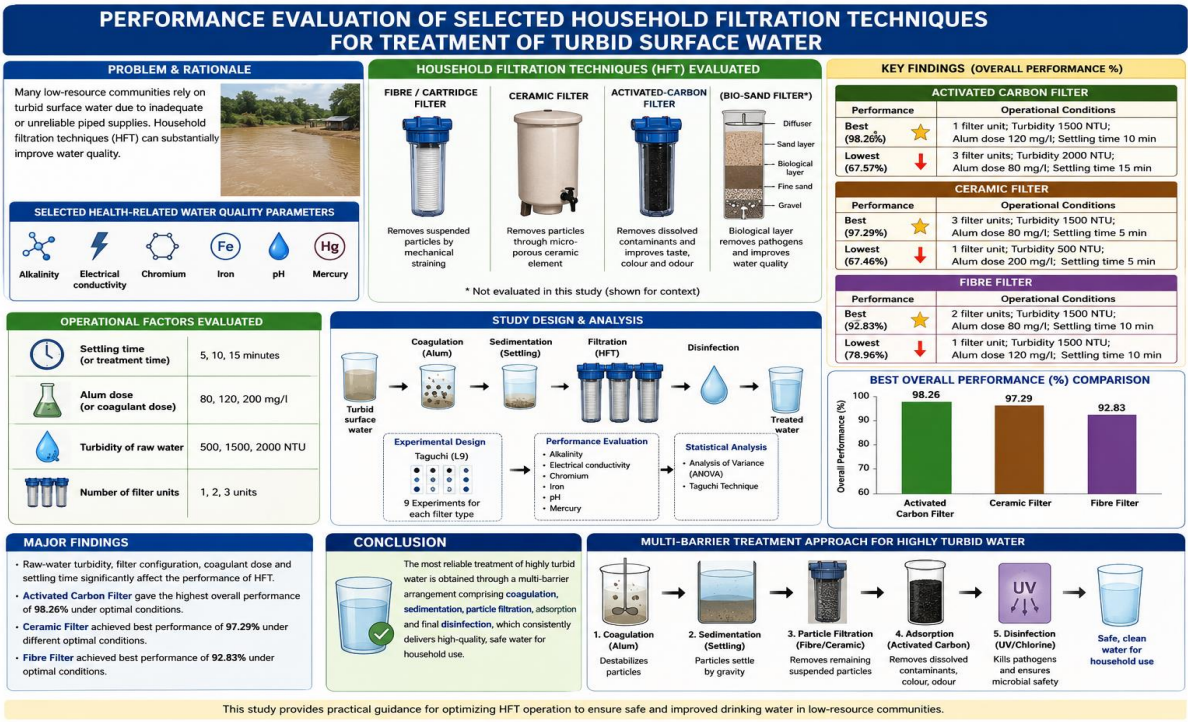
Keywords

Household Water Treatment,
Turbidity,
Fibre Filter,
Ceramic Filter,
Activated Carbon,
Alum,
Sedimentation,
Multistage Filtration.

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Corresponding Author: Oke, I.A, Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria
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Graphic of the Abstract



Abbreviations

ACF means activated carbon filter
APHA means American Public Health Association
AWWA means American Water Works Association
CF means ceramic filter
FF means fibre filter
HFT means Household Filtration Techniques
L_9 4^3 means nine experiments, 4 factors and 3 levels
MDPI means Multi Digital Publication Institute
NTU means Nephelometric Turbidity Unit
RSC means Royal Society of Chemistry
SODIS means solar disinfection
UNICEF means United Nations Children's Fund
UV means Ultraviolet
WHO means World Health Organization
WoS means Web of Science
NBS means National Bureau of Statistics
USEPA means United States Environmental Protection Agency.
EDS means Energy-Dispersive X-ray Spectroscopy (also called Energy-Dispersive X-ray Spectrometry)
SEM means Scanning Electron Microscopy (or Scanning Electron Microscope

INTRODUCTION

The availability of fresh water, or potable water for consumption by living things, is a natural gift that shapes a major part of the world economy. Adequate supplies of this water are necessary for agriculture, human consumption, industry as well as recreation (Sharma and Bhattacharya, 2017; Desye et al., 2023). Figure 1 presents the level of access to safe water worldwide. Contaminated water (surface or groundwater) poses risks to human health and leads to waterborne, water-related, and water-washed diseases (Figure 2), which can be prevented or eliminated with measures even at the household level (Shannon et al., 2008; Fasuan et al., 2025; Gbadebo et al., 2026).

Providing safe water for all is a challenging task worldwide. Surface and groundwater contaminants, which include heavy metals like mercury, copper, chromium, lead, and hazardous chemicals, dyes, and compounds like insecticides and fertilizers, are man-made by-products of industry and agriculture (Stauber et al., 2012; Sadr et al., 2020). In addition, the

presence of clays, colloidal particles, silts or sand, or organic matter, algae, and leaf particles results in turbidity. The turbidity may shield bacteria, preventing disinfection chemicals from attacking and destroying the cells. The presence of organic materials in conjunction with chlorine can form trihalomethanes and other potentially harmful chemicals (Sharma and Bhattacharya, 2017). Generally, surface water sources have higher turbidity compared to groundwater sources. The turbidity of a surface water source can vary greatly from 1 to 200 NTU (Nephelometric Turbidity Unit). The sensitivity to turbidity level is different from children to adults (Brown and Clasen, 2012; Sharma and Bhattacharya, 2017; Bwapwa et al., 2024).

Turbidity is the optical effect produced by suspended clay, silt, organic matter, microorganisms, and other fine particles in water. Although turbidity is not itself a direct measure of toxicity, high turbidity may indicate microbial and chemical contamination, protect microorganisms from disinfection, and reduce the aesthetic acceptability of drinking water. The World Health Organization recommends that turbidity should preferably be below 1 NTU before disinfection; where this cannot be achieved, treatment should aim for less than 5 NTU while applying an appropriately increased disinfectant dose or contact time (WHO, 2017; 2025; Mathur and Chakrabarty, 2025; Medeiros et al., 2020). Household water filtration provides an important decentralised treatment option. However, filtration effectiveness cannot be judged from percentage turbidity removal alone.

A system that reduces turbidity from 2,000 to 20 NTU achieves 99% removal but still produces water above the preferred level for effective disinfection. Performance assessment should therefore consider: percentage removal; final or residual turbidity; microbial removal; changes in pH and dissolved constituents; flow rate and daily water production; filter clogging and operational lifespan; cost, maintenance, and user acceptability; and Potential recontamination during storage (Brown and Clasen, 2012; Huanambal-Sovero et al., 2023; Bwapwa et al., 2024; Gyabaah et al., 2024). Continued research efforts have been ongoing in this area for more than four decades, which have resulted in many processes, methods, technologies, and water treatment techniques (Shannon et al., 2008).

With the current level of access to safe water in Nigeria (Figure 3) and the level of turbid surface water in major rivers in Osun State, Nigeria (Figure 4), there is a need to evaluate the overall performance of household filtration techniques. The main objective of this study is to conduct a report on the performance evaluation of selected HFT (fibre or cartridge filters, ceramic filters, activated-carbon filters) with particular attention to the removal of selected health-related water quality parameters (Alkalinity, Electrical conductivity, Chromium, Iron, pH, and Mercury). Effects of selected operational parameters (settling time or treatment time, alum dose or coagulant dose, turbidity of the raw water, and number of filter units) on the performance were evaluated using Analysis of variance and Taguchi techniques.

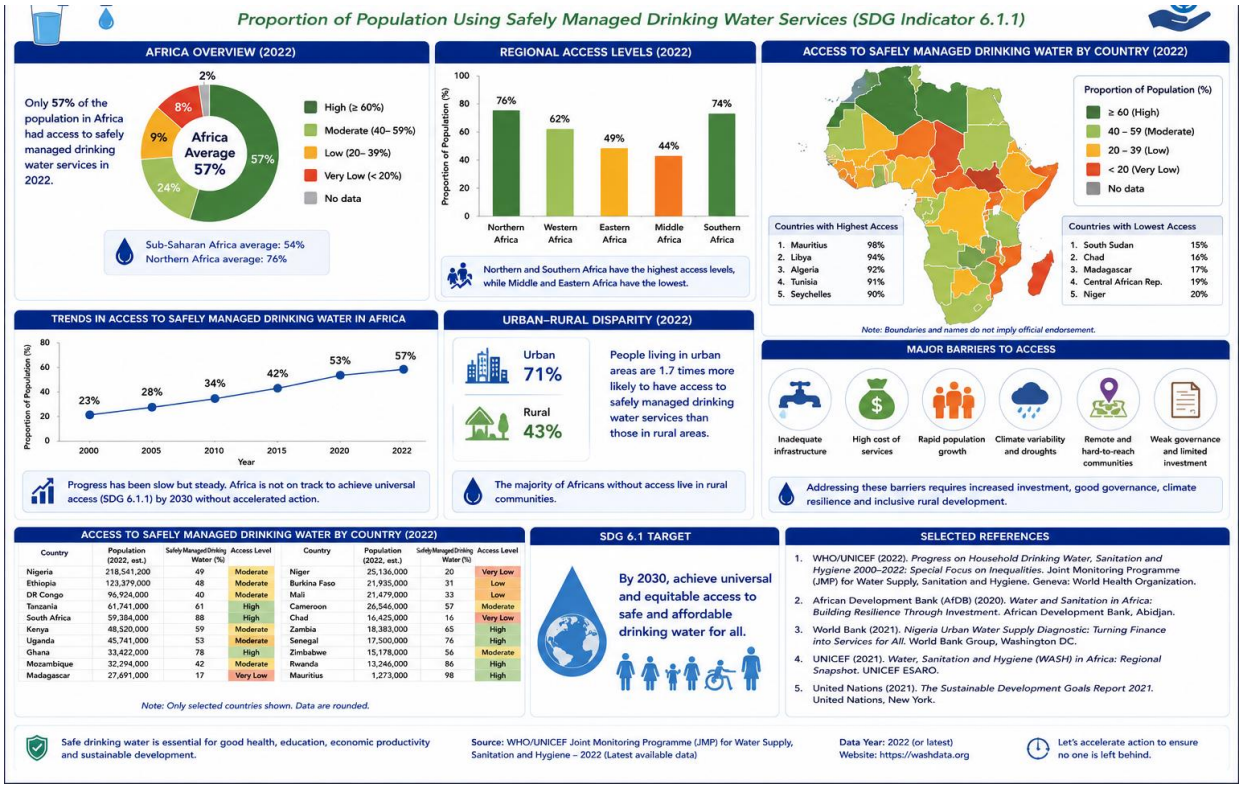


Figure 1a: Access to safe and drinking water in Africa (Adopted from WHO/UNICEF, 2022; 2026; AfDB, 2020, UN, 2021, UNICEF, 2021; World Bank, 2012; Adebajo et al., 2025; Aralu et al., 2025; Azimi and Rahamam, 2026)

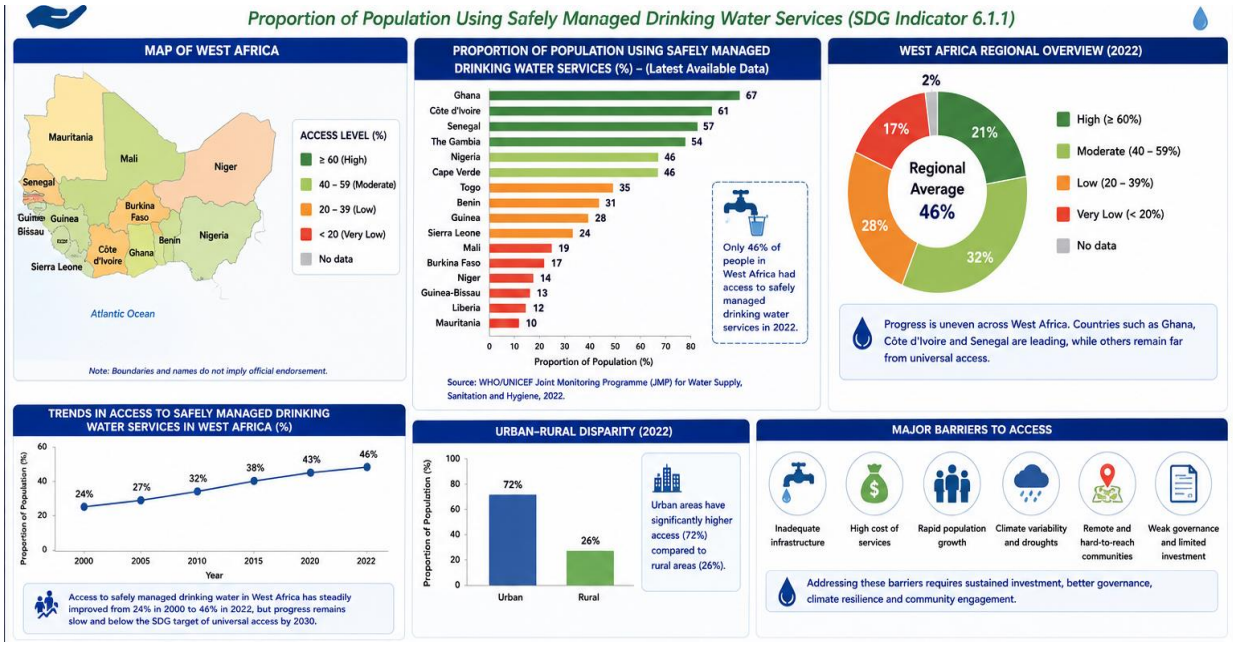


Figure 1b: Access to safe and drinking water in West Africa (Adopted from WHO, 2025; 2026; Yala, 2020; Wolf et al., 2023; Vinca et al., 2026; Vakanicova and Melnyka, 2026)

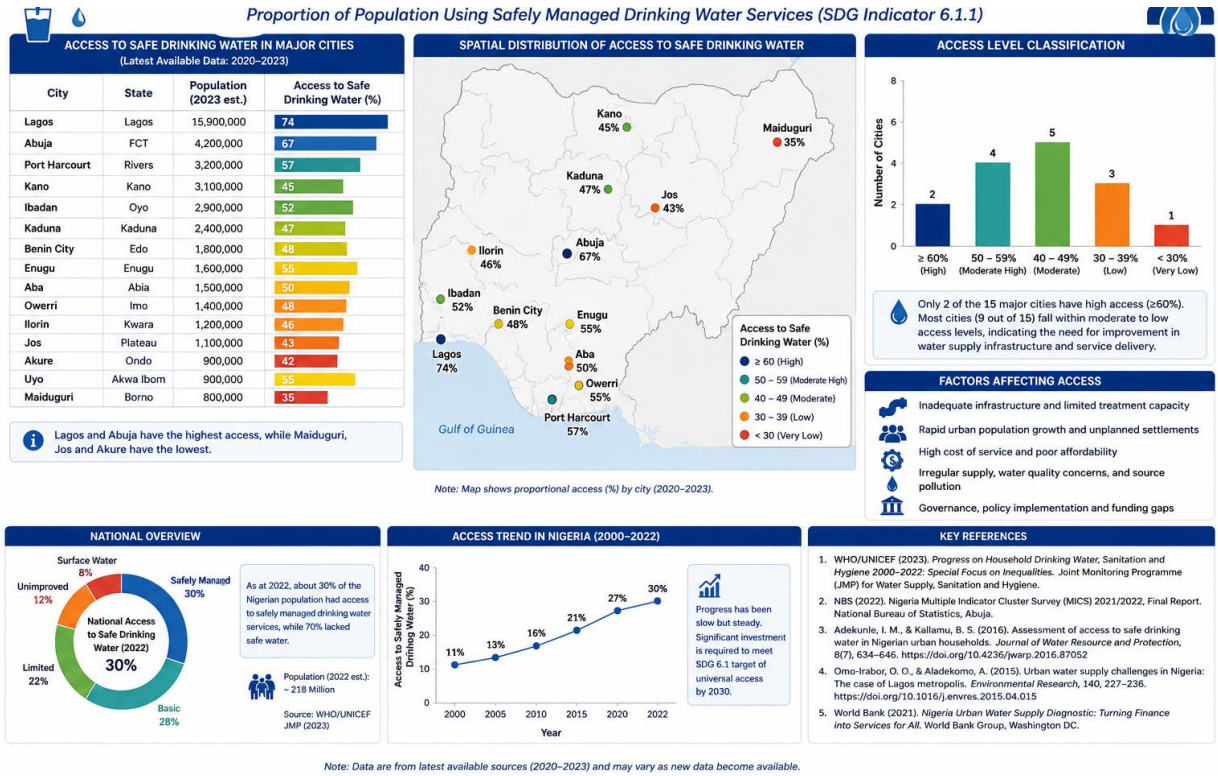


Figure 1c: Access to safe and drinking water in selected cities in Nigeria (Adopted from WHO/ UNICEF, 2023; Adekunle and Kallamu, 2016; NBS, 2022; Omo-Irabor and Aladekomo, 2015; World Bank, 2021; Temre et al., 2026; Mondale et al., 2024; Sadr et al., 2020)

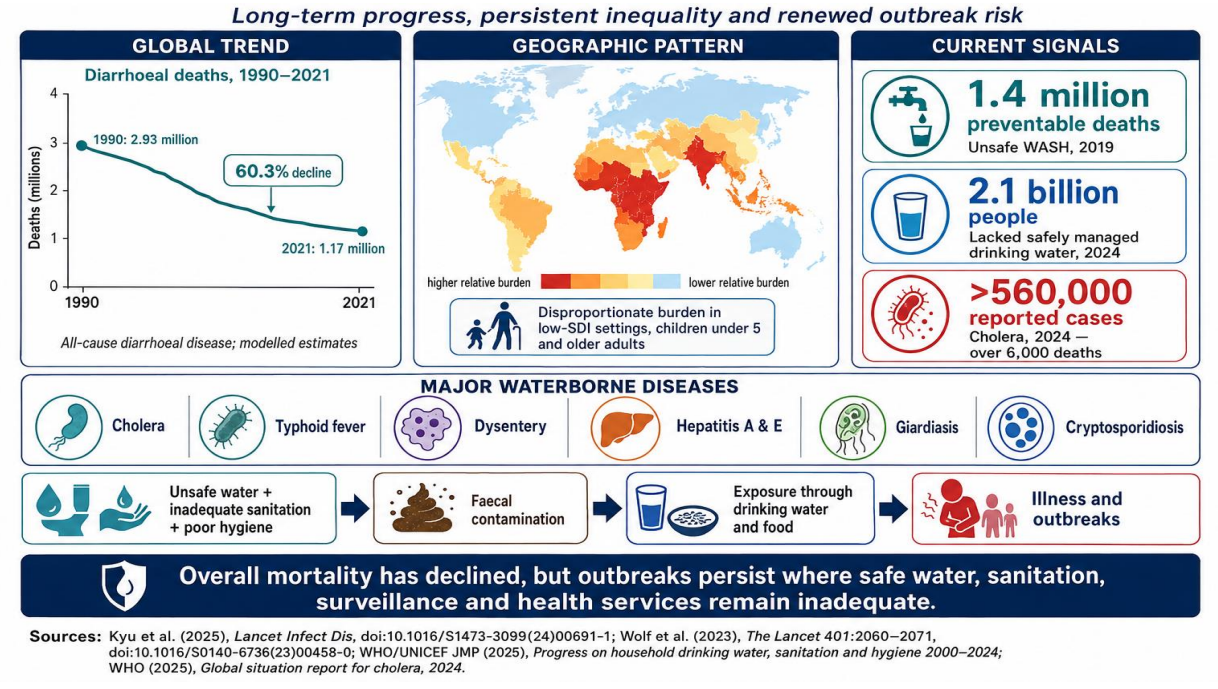


Figure 2: Global Trend and pattern of water borne diseases (Adopted from WHO, 2025; Wolf et al., 2023; Vinca et al., 2026; Kyu et al., 2025; Mondiale de la Santé and World Health Organization,

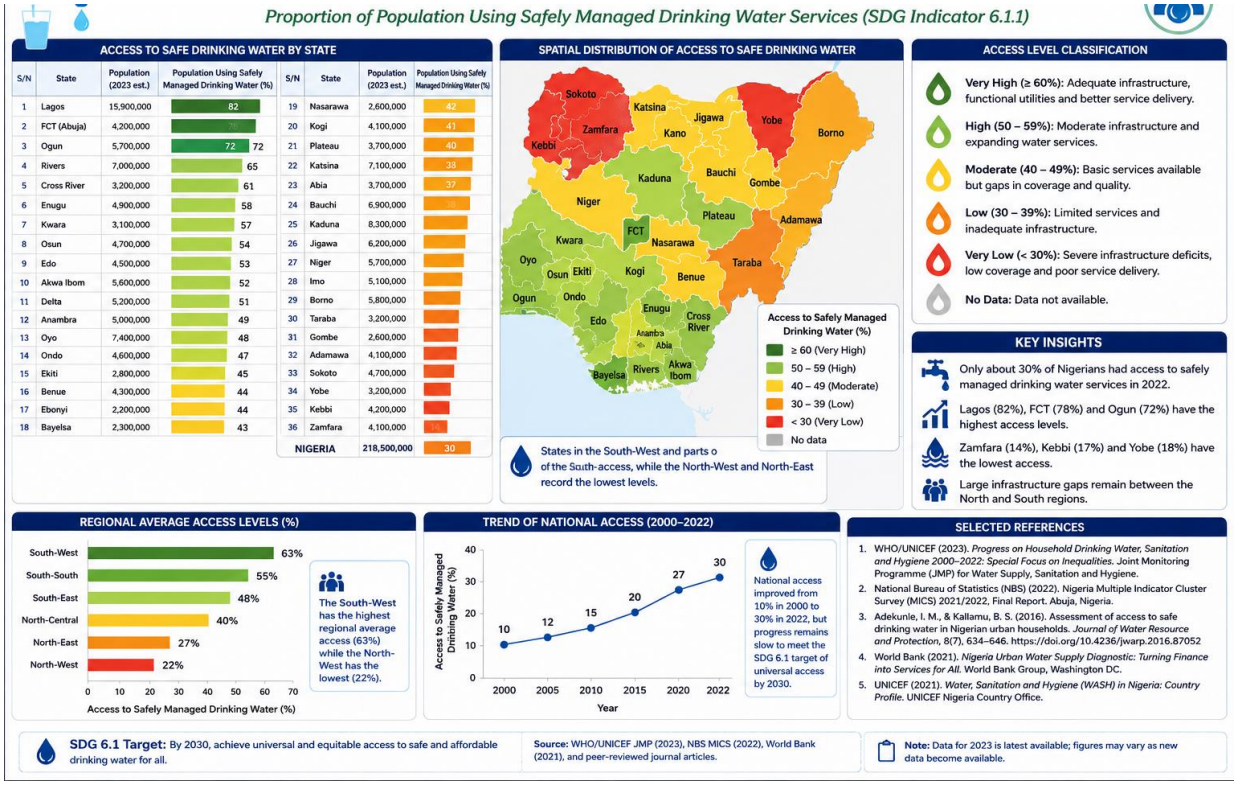
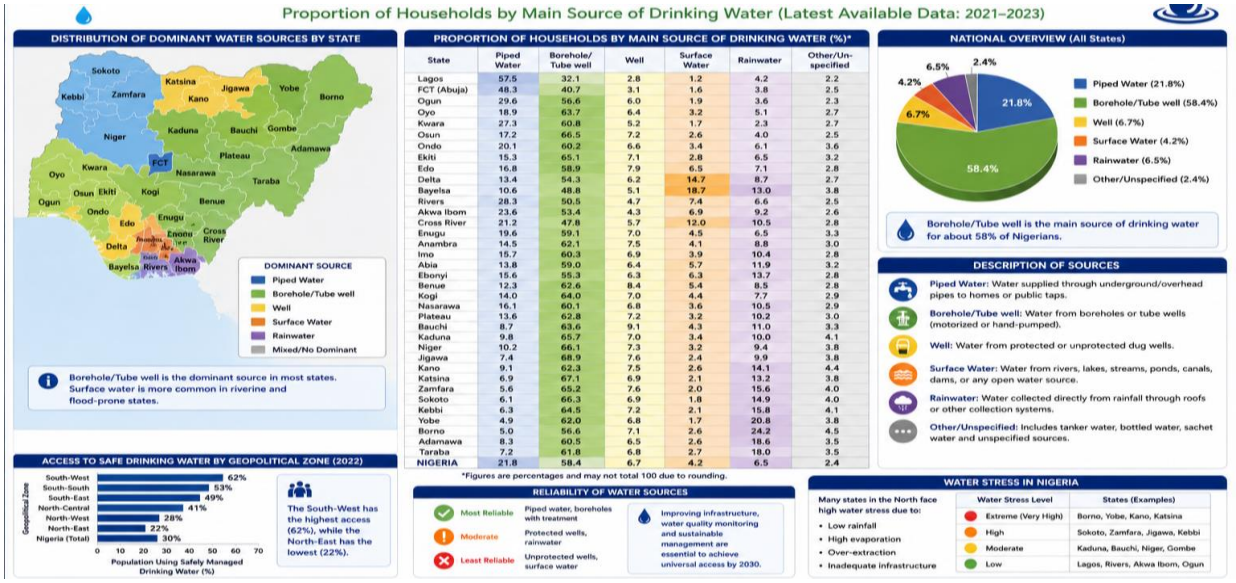


Figure 3a: Access to safe and drinking water in Nigerian States (Adopted from WHO/ UNICEF, 2023; Adekunle and Kallamu, 2016; NBS, 2022; Omo-Irabor and Aladekomo, 2015; World Bank, 2021; Temre et al., 2026; Mondale et al., 2024; Sadr et al., 2020)



State	Piped Water	Borehole/ Tube well	Well	Surface Water	Rainwater	Other/Un-specified
Lagos	57.5	32.1	2.8	1.2	4.2	2.2
FCT (Abuja)	48.3	40.7	3.1	1.6	3.8	2.5
Ogun	29.6	56.6	6.0	1.9	3.6	2.3
Oyo	18.9	63.7	6.4	3.2	5.1	2.7
Kwara	27.3	60.8	5.2	1.7	2.3	2.7
Osun	17.2	66.5	7.2	2.6	4.0	2.5
Ondo	20.1	60.2	6.6	3.4	6.1	3.6
Ekiti	15.3	65.1	7.1	2.8	6.5	3.2
Edo	16.8	58.9	7.9	6.5	7.1	2.8
Delta	13.4	54.3	6.2	14.7	8.7	2.7
Bayelsa	10.6	48.8	5.1	18.7	13.0	3.8
Rivers	28.3	50.5	4.7	7.4	6.6	2.5
Akwa Ibom	23.6	53.4	4.3	6.9	9.2	2.6
Cross River	21.2	47.8	5.7	12.0	10.5	2.8
Enugu	19.6	59.1	7.0	4.5	6.5	3.3
Anambra	14.5	62.1	7.5	4.1	8.8	3.0
Imo	15.7	60.3	6.9	3.9	10.4	2.8
Abia	13.8	59.0	6.4	5.7	11.9	3.2
Ebonyi	15.6	55.3	6.3	6.3	13.7	2.8
Benue	12.3	62.6	8.4	5.4	8.5	2.8
Kogi	14.0	64.0	7.0	4.4	7.7	2.9
Nasarawa	16.1	60.1	6.8	3.6	10.5	2.9
Plateau	13.6	62.8	7.2	3.2	10.2	3.0
Bauchi	8.7	63.6	9.1	4.3	11.0	3.3
Kaduna	9.8	65.7	7.0	3.4	10.0	4.1
Niger	10.2	66.1	7.3	3.2	9.4	3.8
Jigawa	7.4	68.9	7.6	2.4	9.9	3.8
Kano	9.1	62.3	7.5	2.6	14.1	4.4
Katsina	6.9	67.1	6.9	2.1	13.2	3.8
Zamfara	5.6	65.2	7.6	2.0	15.6	4.0
Sokoto	6.1	66.3	6.9	1.8	14.9	4.0
Kebbi	6.3	64.5	7.2	2.1	15.8	4.1
Yobe	4.9	62.0	6.8	1.7	20.8	3.8
Borno	5.0	56.6	7.1	2.6	24.2	4.5
Adamawa	8.3	60.5	6.5	2.6	18.6	3.5
Taraba	7.2	61.8	6.8	2.7	18.0	3.5
NIGERIA	21.8	58.4	6.7	4.2	6.5	2.4

Figure 3b: Various water Sources in Nigerian ststes (Adopted from WHO/ UNICEF, 2023; Adekunle and Kallamu, 2016; NBS, 2022; Omo-Irabor and Aladekomo, 2015; World Bank, 2021; Temre et al., 2026; Mondale et al., 2024; Sadr et al., 2020)



Figure 4a: Aerial view of turbid water from Opa River (Source: Google Earth Pro, 2026)

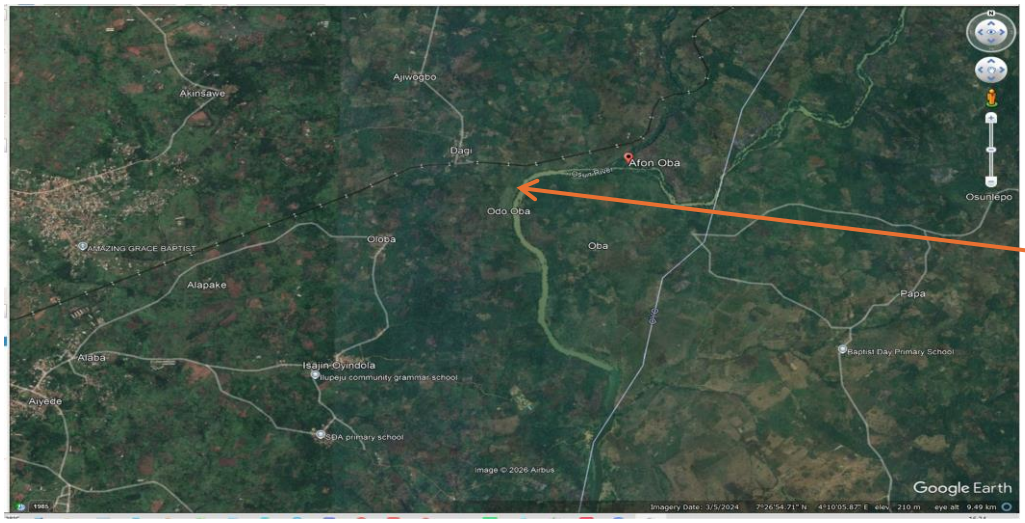


Figure 4b: Aerial view of turbid water from Oba River (Source: Google Earth Pro, 2026)



Figure 4c Aerial view of turbid water from Osun River (Source: Google Earth Pro, 2026)

MATERIALS AND METHODS

In this study on household water filtration techniques, the issues and challenges related to potable water production problems were explored. Recent and relevant information and data such as numerical values, figures and images were mined and composed from relevant databases utilizing several search engines and links such as PubMed link; Taylor and Francis Online link, ScienceDirect link, Scopus link, Google Scholar link, Web of Science (WoS) link, Wiley Online Library link, Elsevier link, SpringerLink, American Chemical Society Publications link, Magiran link, Multi Digital Publication Institute (MDPI) link, Frontiersin link, and Royal Society of Chemistry (RSC) Publishing link utilising the keywords such as potable water, household treatment, drinking water, water demand, water stress, water scarcity, water supply progression, trend of water supply, contaminated water, communicable disease, water borne diseases and water based disease, individually and in combination.

In summary, a desktop review was conducted using these keywords. Specific options were selected (any publication time, any article type, including patient articles and citations), and for publication growth, the selected options include relevance, any time, patient articles, review articles, and citations. In addition, selected operational factors (number of filters, type of filter (Ceramic filter CF, Fibre filter FF, and Activated Carbon Filter, ACF) alum dosage, turbidity of the raw water, and settling time after coagulation) that impacted the performance of household water treatment were studied and optimised using Taguchi techniques (L_9 4^3, Table 1), SEM and EDS of the coagulant used were conducted, and typical surface water collected from Opa River (Aladekomo, 2025; Aladekomo et al., 2026).

These water samples were mixed with coagulant rapidly and slowly, and allowed to settle for the settling time (Wang et al., 2021; Adejuwon et al., 2025). Figure 5 presents the location of sampling points. Figure 6 shows the laboratory setup. The outcomes of the literature search, data, and household treatment performance were analysed statistically using Microsoft Excel, and the effects of selected factors on the system's performance trend were identified and quantified. The performance (individual and overall) of HFT based on the ability to remove selected pollutants (Alkalinity, Electrical conductivity, Chromium, Iron, pH, and Mercury) was computed as follows (equations 1 and 2):

$$P_i = 100\left(1-\frac{Y_f}{Y_i}\right) \quad (1)$$

$$P_a = \left(P_1 \times P_2 ----------\times P_n\right)^{\frac{1}{n}} \quad (2)$$

RESULTS AND DISCUSSIONS

Results from this study are discussed in the following categories: desktop review on household water filtration techniques and performance of selected Household Water Filtration Techniques. The results are presented as follows:

a) Desktop Review on Household Water Filtration Techniques

From the desktop review, the performance of specific household filtration techniques and effects of specific parameters on the performance are presented and discussed as follows:

B The Performance of Specific Household Water Filtration Techniques: The performance of the specific household water filtration techniques established in literature is presented as follows:

C Fibre and cartridge filtration: Fibre filters, including cotton cloth, woven fabric, polypropylene cartridges and other fibrous materials, remove particles mainly through surface straining, interception and entrapment within the fibre matrix. Fibre filters are inexpensive, simple to operate and suitable as pretreatment units for highly turbid water (Inusah et al., 2026; Isukuru et al., 2024; Iturralde Carrera et al., 2025; Jellali et al., 2024). The principal strengths of fibre filters are rapid removal of coarse suspended solids; Protection of finer ceramic, carbon or membrane filters; Low initial cost; and Simple replacement or washing. It is well known that fibre filtration treatment technique alone normally provides inadequate removal or reduction of very fine suspended colloids, dissolved chemicals, suspended solids and microorganisms (Chollom et al., 2017; Chollom et al., 2019; Clasen, 2015). However, the performance or efficacy improves or increases as retained solids or particles form a filter cake, which causes an increase in the head loss and reduces the flow rate and volume of treated water.

Some studies on low-cost cartridge filters established that two or more pleated filters arranged in series could enhance the performance or achieve very high turbidity removal after cake formation. This therefore demonstrates the importance of filter configuration and progressive particle retention (Sobsey et al., 2008; Brown and Clasen, 2012; Afkhami et al., 2021; Mathur and Chakrabarty, 2025). It can be highlighted that fibre filters should be regarded predominantly as pre-treatment barriers rather than a complete household drinking-water treatment or purification system.

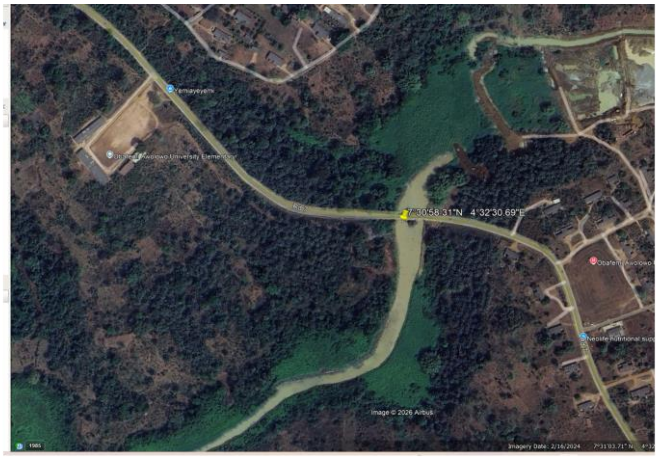


Figure 5a: An aerial view of the location for sampling point A
(Source: Aladekomoo et al., 2026; Google Earth Pro, 2026)

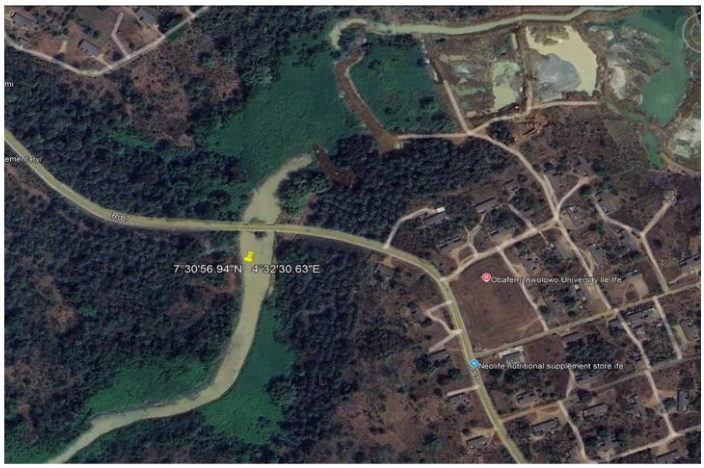


Figure 5b: An aerial view of the location for sampling point B
(Source: Aladekomoo et al., 2026; Google Earth Pro, 2026)

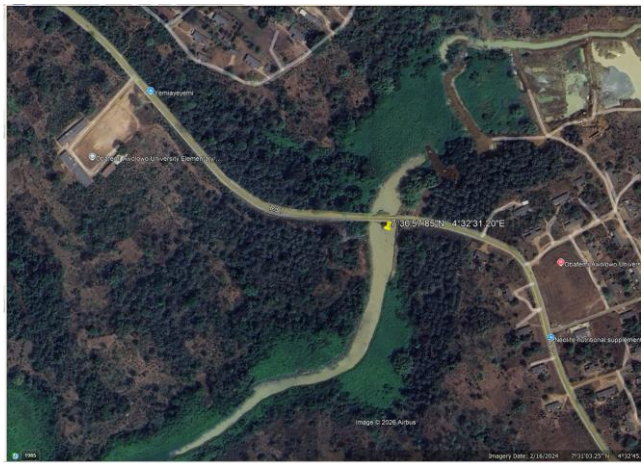


Figure 5c: An aerial view of the location for the sampling point C
(Source: Aladekomoo et al., 2026; Google Earth Pro, 2026)



Figure 6a Laboratory Set-up for Ceramic Filtration Unit

Figure 6b: Laboratory Set-up for Activated Carbon Filtration Unit

Figure 6c: Laboratory Set-up for fibre filtration unit

Figure 6: Laboratory Set-up for filtration units (Aladekomoo et al., 2026)

Table 1: Taguchi $L_9 4^3$ Orthogonal Array for Experimental Design (Aladekomoo et al., 2026)

Experiments	Factors and Levels				Factors and Values			
	A (No of filter unit)	B (Turbidty)	C (Alumn Dose)	D(Settling Time)	A (No of filter unit)	B (Turbidty, NTU)	C (Alumn Dose, mg/l)	D(Settling Time, minutes)
1	1	1	3	1	1	500	200	5
2	2	3	3	2	2	2000	200	10
3	3	3	3	1	3	2000	200	5
4	1	1	2	3	1	500	120	15
5	3	2	1	1	3	1500	80	5
6	3	3	1	3	3	2000	80	15
7	1	2	2	2	1	1500	120	10
8	2	2	1	2	2	1500	80	10
9	2	1	2	3	2	500	120	15

a. **Ceramic filtration:** Ceramic filters are frequently manufactured and developed from fired clay assorted with combustible substances or materials such as rice husk, corn cob, or sawdust or millet husk. Burning or fractional destruction of these organic materials creates pores through which water can easily pass under gravity. Suspended particles, solids, and microorganisms are eliminated in this system, principally by size exclusion, adsorption and tortuous movement, transport, or flow through the ceramic medium or structure. Ceramic filters provide high turbidity, solids (suspended, settleable or floating), bacterial, and other microorganism removal (Chollom et al., 2017; Chollom et al., 2019; Clasen, 2015).

   Effectiveness of these systems varies with pore-size distribution, firing set temperature, hydraulic head, raw-material component and composition, ceramic wall thickness, quality of the raw water, and flow rate of the water. Silver impregnation into the filter is known to improve or enhance microbial inactivation but could not replace specific operation and hygienic storage (Mahlangu et al., 2012; Kearns et al., 2019; Jellali et al., 2024; Jiménez and Arrojo-Agudo, 2026). Ceramic-filter studies have reported and established turbidity reductions ranging from approximately 30% to almost complete removal from initial water quality, depending on filter characteristics and influent water quality (Mathur and Chakrabarty, 2025; Medeiros et al., 2020; Mahlangu et al., 2012). Field studies conducted in Cambodia demonstrated that locally developed and manufactured ceramic filters substantially improved microbial water quality and reduced diarrhoeal disease in participating households in the studies (Brown et al., 2008). Brown and Sobsey (2010) revealed that ceramic-filter efficacy and performance depend on other operational factors such as manufacturing quality, filter age, flow rate, cleaning and household handling practices (Brown and Sobsey, 2010; Latif et al., 2026; Lantagne et al., 2021; 2026). High influent turbidity may rapidly block ceramic pores. Consequently, coagulation, sedimentation or fibre prefiltration is advisable before ceramic filtration when raw water is extremely turbid.

b. **Activated-carbon filtration:** Activated carbon contains a highly porous internal surface that adsorbs many dissolved organic compounds. It is particularly effective for reducing: taste and odour compounds; residual chlorine; selected pesticides and volatile organic compounds; natural organic matter; some metals, depending on water chemistry and carbon modification; and colour-producing dissolved substances. Activated carbon should not, however, be treated primarily as a turbidity-removal medium (Cornell and Kelly-Hope, 2025; Crini et al., 2026; Das, 2025). Large quantities of suspended solids can coat its surface, block pores and shorten its adsorption lifespan.

   The United States Environmental Protection Agency identifies granular activated carbon as an effective technology for numerous organic contaminants, but its efficiency depends on empty-bed contact time, carbon properties, contaminant concentration and media replacement (Duran Romero et al., 2020; Egbueri et al.,

2024; USEPA, 2026). Activated carbon normally performs best after coagulation, sedimentation and particle filtration. Its role in a household treatment train is to polish water already clarified by fibre, sand or ceramic media. Activated Carbon filters must be replaced or regenerated after some time because inactive or exhausted carbon as a filter medium can cease to remove or reduce contaminants and can support microbial growth due to the carbon source in the filter medium if not properly maintained.

c. **Bio-sand and slow-sand filtration:** A bio-sand filter entails fine sand, coarser sand and gravel ((Duran Romero et al., 2020; Egbueri et al., 2024; USEPA, 2026). Contaminants in water are removed by a bio-sand filter through straining, sedimentation, adsorption and biological activities in the surface layer of the filter. Bio-sand filters are known to be relatively inexpensive, require no electricity as power or energy source, and can purify moderate quantities of household water (Lantagne et al., 2021; Laouane et al., 2026; Latif et al., 2025).

   A field trial conducted in Tamale, Ghana, reported an average turbidity removal or reduction of approximately 67% and a 97% removal or reduction in *E. coli* in treated water collected directly from plastic bio-sand-filter outlets. In addition, the microbial quality declined or deteriorated during subsequent household storage, indicating that filtration performance of bio-sand filters can be undermined by recontamination of treated water (Stauber et al., 2012). Bio-sand-filter performance is influenced by some operational factors such as sand effective size, filter media depth, hydraulic rate and loading, pause and treatment period, filter age and maturity, concentration of floc or solids (suspended, settleable and floating) and influent turbidity. Bio-sand filter may not be able to consistently produce treated water quality of below 5 NTU when the raw water source is extremely turbid water and is introduced into the filter without pretreatment such as coagulation and flocculation (Duran Romero et al., 2020; Egbueri et al., 2024; USEPA, 2026).

d. **Membrane and combined household systems:** Microfiltration and ultrafiltration membranes as water treatment systems can produce treated water quality of very low turbidity because of their lower pore sizes, which provide a well-defined physical barrier. It is well established that small-scale membrane systems have produced filtrate of water quality below 1 NTU at several different influent turbidity levels (Alfa et al., 2016). The key limitations of these systems are membrane fouling, cleaning requirements, replacement costs, availability in rural areas and, for some systems, pressure or electricity demand. In these systems, pretreatment is especially important when the raw water contains high suspended-solids concentrations (Cornell and Kelly-Hope, 2025; Crini et al., 2026; Das, 2025).

   Multistage utilisation of these systems is generally more robust. Research and studies on household multistage filtration established that gravel pretreatment combined with finer filtration reduced turbidity and *E. coli* more reliably than a single filtration stage (Medeiros et al.,

2020). Table 2 presents a comparison of selected parameters of these selected filters.

A. **Effects of Selected Operational Parameters and Factors on the Performance of Specific Household Water Filtration Techniques from Desktop Review:** Effects of selected operational parameters and factors on the performance of specific household filtration techniques are explained as follows:

i. **Initial turbidity:** Initial turbidity influences both apparent removal efficiency and filter sustainability. Highly turbid water contains more particles that can collide, aggregate, and become trapped in a filter. This may produce high percentage removal during the early treatment period. However, turbidity also causes rapid filter-cake formation; greater head loss; reduced flow; shorter operational cycles; more frequent cleaning; and possible particle breakthrough. Consequently, high percentage removal at 1,500 NTU to 2,000 NTU does not necessarily mean that the final water is safe or that the filter can sustain the performance. Residual turbidity must be reported alongside percentage removal (Aunkham et al., 2026; Idigbe et al., 2024; Chollom et al., 2017; Chollom et al., 2019; Clasen, 2015).

ii. **Alum dose:** Aluminium sulphate destabilises negatively charged colloids and promotes the formation of settleable flocs. Increasing alum dose usually improves turbidity removal until an optimum dose is reached. Below the optimum, insufficient charge neutralisation produces small, poorly settling flocs. Above it, charge reversal, excess residual aluminium, increased sludge production and pH reduction may occur (Cornell and Kelly-Hope, 2025; Crini et al., 2026; Das, 2025). Coagulation performance therefore follows an optimum rather than a continuously increasing relationship. The required dose depends on initial turbidity, pH, alkalinity, temperature and particle characteristics. Reviews of coagulation–flocculation confirm that inadequate or excessive dosing can compromise treatment efficiency and final water quality (Jiménez and Arrojo-Agudo, 2026; Kearns et al., 2019; Beshir et al., 2025; Tahraoui et al., 2024). Thus, alum doses such as 80, 120 and 200 mg/L should not be interpreted independently of turbidity and pH.

iii. **Settling time:** Settling time after coagulation and flocculation processes allows coagulated particles or flocs to separate from the water before the treated water reaches the filter. Increasing or higher settling time usually reduces the suspended or settleable solids loading on household filters and delays clogging of the filter (Cornell and Kelly-Hope, 2025; Crini et al., 2026; Das, 2025). Nevertheless, with higher settling time, most of the settleable flocs in the pretreated water are removed through the higher settling period or during the early sedimentation period, after which additional settling creates or produces progressively smaller benefits through further removal of flocs. A short settling period only allows fragile flocs to enter the filter unit and block the filter. An excessively long settling period reduces daily treatment capacity and encourages

contamination in the case of an uncovered settling vessel or tank. It is best practice to optimise the settling time to consistently provide adequate clarification of the treated water **(**Al-Himeiri and Al-Fatlawi, 2022; Baumgartner et al., 2007; Beck et al., 2021).

iv. **Number of filter units:** It is well established that an increase in the number of treatment units improves the performance of the filter through the provision of greater media depth, surface area and contact time. The sequential or arrangement of these filters may be specialised in different functions such as a fibre filter unit for coarse-particle removal; a ceramic or sand unit for fine particles and micro-organisms removal; and an activated-carbon filter unit for dissolved organic compounds, taste, odour and colour reduction (Cornell and Kelly-Hope, 2025; Crini et al., 2026; Das, 2025). However, an increase in the number of identical filters may not automatically produce equivalent or proportional improvement. In addition, additional filter units increase head loss and hydraulic load, reduce flow, raise capital and operational costs, and create more surfaces that require cleaning or maintenance. The benefit is more on complementary treatment functions than simply on filter number (Rytwo et al., 2026; Goudjil et al., 2024).

v. **Filtration rate and contact time:** A low filtration rate and high contact time normally increase particle retention time and the adsorption process because the treated water remains in contact with the filter media for a longer period of time. A high filtration rate and low contact time can force particles or flocs through pores, disturb deposited solids, and shorten activated-carbon contact time as well as performance. Conversely, an excessively low flow can fail to supply adequate and appropriate daily household water demand. Performance optimisation of these two operational factors must therefore balance removal efficiency against water-production capacity (Belkacemi et al., 2026; Aitbara et al., 2026).

Table 2: A comparison of selected parameters of these selected filters

Filtration technique	**Principal mechanism**	**Turbidity performance**	**Main limitation**	**Appropriate role**
Fibre or cartridge	Straining and cake filtration	Good for coarse particles; variable for colloids	Rapid clogging and limited microbial removal	Pretreatment
Ceramic	Size exclusion and adsorption	Generally high when pores are intact	Low flow and pore blockage	Fine filtration and microbial barrier
Activated carbon	Adsorption and some depth filtration	Moderate alone; better after clarification	Exhaustion and biological growth	Chemical and aesthetic polishing
Bio-sand	Physical, chemical and biological removal	Moderate to high, depending on maturity and loading	Requires maturation and controlled flow	Main household filtration unit
Membrane	Size-selective separation	Very high, often producing low-turbidity filtrate	Fouling, cost and maintenance	High-quality final filtration
Multistage system	Sequential removal mechanisms	Usually most stable under variable conditions	Greater complexity and initial cost	Comprehensive household treatment

Table 3: The performance evaluation of Activated Carbon Filter

Experiments	A (No of filter units)	B (Turbidity)	C (Alum Dose)	D(Settling Time)	Alkalinity Removed (%)	Electrical Conductivity Change (%)	Chromium Removed (%)	Iron Removed (%)	pH Change (%)	Mercury Removed (%)	Overall Performance
1	1	500	200	5	98.00	95.00	142.00	107.00	42.00	100.00	91.69
2	2	2000	200	10	97.00	93.00	142.00	107.00	39.00	100.00	90.09
3	3	2000	200	5	97.00	86.00	141.00	105.00	20.00	100.00	79.21
4	1	500	120	15	98.00	52.00	142.00	107.00	68.00	100.00	89.86
5	3	1500	80	5	98.00	90.00	142.00	107.00	-14.00	100.00	75.66
6	3	2000	80	15	90.00	87.00	142.00	107.00	-8.00	100.00	67.57
7	1	1500	120	10	99.00	88.00	142.00	107.00	68.00	100.00	98.26
8	2	1500	80	10	96.00	88.00	142.00	107.00	14.00	100.00	75.12
9	2	500	120	15	96.00	52.00	142.00	107.00	46.00	100.00	83.90
									Average		83.49

vi. **Filter maintenance and storage:** Accumulated solids or flocs must be periodically removed or eliminated by washing, scraping, or replacing the filter media. Poor cleaning of filter media can cause severe flow reduction, while overly aggressive cleaning may damage ceramic surfaces of the filter or remove the biologically active layer of a bio-sand filter. In addition, safe storage of treated water is equally critical and important. Filtered or treated water should be collected in a clean, covered, narrow-necked container fitted with a tap. The Ghana bio-sand-filter trial study established considerably higher *E. coli* concentrations in stored filtered water than in samples collected directly from the filter outlet, which confirms the importance of post-treatment hygiene (Stauber et al., 2012; Beshir et al., 2024).

b) Performance of selected Household Water Filtration Techniques

Table 3 presents the performance of the Activated Carbon Filter from this study. The Table shows that the treatment system produced consistently high alkalinity, chromium, iron, and mercury responses, while electrical conductivity and pH changed considerably across the operating conditions. Overall performance ranged from 67.57% to 98.26%. Experiment 7 produced the best overall result, whereas Experiment 6 produced the lowest. Experiment 7 achieved the highest overall performance using one filter unit, intermediate turbidity, an intermediate alum dose, and a settling time of 10 minutes. This indicates that increasing the number of filters, alum dose or settling time to their maximum levels was unnecessary under the conditions investigated. The breakdown of the performance of the system from the Table is as follows:

a) **Alkalinity removal:** Alkalinity removal by ACF ranged from 90% to 99%, showing that the system was highly effective in reducing the water's buffering constituents. Experiment 7 produced the highest alkalinity removal of 99%. Experiments 1, 4 and 5 followed closely at 98%. The lowest value, 90%, occurred in Experiment 6.

The high removal may be attributed to the reaction between alum and bicarbonate alkalinity: During this reaction, alkalinity is consumed and gelatinous aluminium hydroxide flocs are formed. These flocs adsorb contaminants and trap suspended particles. The narrow range between 90% and 99% indicates that alkalinity removal was relatively stable and uniform across these different treatment conditions. However, the lower value of overall performance in Experiment 6 indicates that a combination of high turbidity and a low alum dose can not provide sufficient coagulant relative and enough to the treatment of the turbidity and contaminants load.

b) Electrical conductivity change: Electrical conductivity change by ACF was one of the most variable responses, ranging from 52% to 95%. Experiment 1 provided the highest conductivity change of 95 %, followed by Experiment 2 at 93% and Experiment 5 at 90%. Experiments 4 and 9 resulted in the lowest values of 52%. If these values represent percentage reductions, Experiment 1 was the most effective at removing or reducing dissolved ionic constituents. Possible

mechanisms include: adsorption of ions onto alum flocs; precipitation of metal ions; entrapment of ionic contaminants associated with particles; and filtration of coagulated material. However, alum introduces aluminium and sulphate ions into water, which can increase conductivity if excess alum remains after treatment. Consequently, the column should be identified clearly as either conductivity reduction, conductivity increase or absolute percentage change. Experiments 4 and 9 had identical operating conditions for turbidity, alum dose and settling time but differed in the number of filter units. Both produced a conductivity response of 52%. This suggests that, under these conditions, the low conductivity response was more closely associated with the combination of low turbidity, intermediate alum dose and long settling time than with the number of filters.

c) **Chromium removal:** The reported chromium response or removal by ACF ranged from 141% to 142%, showing almost no variation among the experiments. Experiment 3 gave 141%, while all the other experiments gave 142%. Chromium can be removed by: adsorption on aluminium hydroxide flocs; surface complex formation; co-precipitation with metal hydroxides; entrapment of chromium-bearing particles; and retention within filter media. The nearly constant values suggest that chromium treatment was not strongly affected by the investigated factor levels.

d) **Iron removal:** Iron removal by ACF ranged from 105% to 107%. Experiment 3 gave 105%, while every other experiment gave 107%. Iron removal may occur through oxidation and precipitation as insoluble iron hydroxide:

$$Fe^{3+} + 3OH^{-} \rightarrow Fe\left[OH\right]_3 \quad (3)$$

The precipitated iron hydroxide can become incorporated into alum flocs and subsequently be removed by settling and filtration. The results suggest that the system maintained a strong and stable iron-removal response. However, the values above 100% are physically impossible when expressed as conventional removal efficiencies. The lack of meaningful variation also suggests possible rounding, model-generated values, normalization or spreadsheet duplication.

e) **pH change:** The pH response of ACF ranged from –14% to +68%. Unlike the other responses, treatment caused both decreases and increases in pH. The largest positive pH changes of 68% occurred in Experiments 4 and 7. Experiment 9 recorded a positive change of 46%. Experiment 1 recorded a positive change of 42%. The largest negative change, –14%, occurred in Experiment 5. Experiment 6 recorded –8%. Positive values presumably indicate that the final pH was higher than the initial pH, while negative values indicate acidification. If this interpretation is correct, the low alum dose of 80 was generally associated with smaller or negative pH changes, whereas the intermediate and high doses produced positive changes in several experiments. This trend or pattern is unusual because alum hydrolysis usually

releases hydrogen ions and thus reduces pH as follows:

$$Al^{3+} + 3H_2O \rightarrow Al[OH]_3 + 3H^+ \quad (4)$$

f) **Mercury removal:** Mercury removal by ACF in the treated water was reported as exactly 100% in all nine (9) experiments. This performance suggests a complete removal or reduction of mercury below the analytical detection limit, regardless of the operating conditions by ACF. Potential mechanisms of mercury removal by ACF can be any or a combination of these factors: adsorption onto aluminium hydroxide flocs; co-precipitation; attachment to suspended particles; physical entrapment within filter media; and settling of mercury-bearing flocs in the treated water. The constant result of mercury removal indicates that mercury removal was not measurably sensitive to filter number, turbidity, alum dose or settling time. In summary, the overall performance of ACF appears to be strongly influenced by the pH response. Experiment 7 had a pH change of +68% and the highest overall score; Experiment 4 also had a pH change of +68% and achieved 89.86%; Experiments 5 and 6 had negative pH changes and relatively low overall scores; and Experiment 8 had a small positive pH change and an overall performance of only 75.12%. This pattern and trend of change suggest that the overall-performance calculation may reward positive pH change and penalize negative change.

Tables 4 and 5 show the performance evaluation of the ceramic filter and the performance evaluation of fibre filter, respectively. From Table 4, the experimental results show consistently strong treatment of alkalinity, iron and mercury, but greater variation in electrical conductivity, chromium response, and pH. Overall performance ranged from 77.46% to 97.29%. Experiment 5 was the best treatment condition, while Experiment 1 produced the lowest overall performance. Seven experiments out of the nine experiments achieved overall performance above 90% by CF. The Table revealed that the treatment system was commonly effective across a broad range of operational factors and conditions. The differences among the runs or experiments indicate that treatment performance of CF depended on the combination of the number of filter units, turbidity of the influent, coagulant (alum) dose, and settling or contact time rather than depending on a single factor. The details of the performance of CF and an explanation of the performance are as follows:

a. **Alkalinity removal:** Alkalinity removal by CF ranged from 88% to 97%. This performance of CF demonstrates that the treatment process utilising CF substantially reduced or enhanced the water's buffering constituents. Experiment 1 recorded the highest alkalinity removal or reduction by CF of 97%, followed by Experiment 3 at 96 % and Experiment 9 at 94 %. Experiment 4 performance by CF was the lowest value of 88%, which was still relatively high. This high alkalinity removal by CF can be attributed primarily to alum hydrolysis. It is known that alum, as a coagulant, reacts with bicarbonate alkalinity to form insoluble aluminium hydroxide flocs as follows:

$$Al_2[SO_4]_3 + 6HCO_3^- \rightarrow 2Al[OH]_3 + 6CO_2 \quad (5)$$

This reaction between alum and carbonates consumes bicarbonate alkalinity while producing flocs that adsorb and trap some of the contaminants. Consequently, alum coagulation simultaneously supports contaminant removal and reduces alkalinity. The highest alkalinity removals of the treatment system with CF occurred at an alum dose of 200 mg/l. Experiment 1 achieved 97% alkalinity removal through this CF treatment system but had the lowest overall performance. This performance shows that optimizing alkalinity alone would not produce or generate the best multi-parameter treatment condition.

b. **Electrical conductivity (EC) change:** Electrical conductivity response in the system with CF ranged from 67% to 86%. This performance is one of the most variable treatment responses or performance. The highest performance of CF in respect of electrical conductivity changes of **86%** occurred in Experiments 7 and 8, while Experiment 3 produced the lowest performance value of **67%**, followed by Experiment 9 with a performance of **71%**. This result shows that this treatment system with CF influences electrical conductivity through two competing mechanisms: precipitation, coagulation, and filtration remove dissolved or particle-associated ions.

Table 4: The performance evaluation of Ceramic Filter

Experiments	A (No of filter units)	B (Turbidity)	C (Alum Dose)	D (Settling Time)	Alkalinity Removed (%)	Electrical Conductivity Change (%)	Chromium Removed (%)	Iron Removed (%)	pH Change (%)	Mercury Removed (%)	Overall Performance
1	1	500	200	5	97.00	82.00	141.00	107.00	-18.00	100.00	77.46
2	2	2000	200	10	90.00	84.00	142.00	107.00	-56.00	100.00	92.91
3	3	2000	200	5	96.00	67.00	90.00	107.00	-64.00	100.00	85.71
4	1	500	120	15	88.00	81.00	142.20	107.00	-66.00	100.00	94.58
5	3	1500	80	5	91.00	84.00	142.00	107.00	-73.00	100.00	97.29
6	3	2000	80	15	89.00	83.00	142.00	107.00	-52.00	100.00	91.42
7	1	1500	120	10	93.00	86.00	142.00	107.00	-61.00	100.00	95.13
8	2	1500	80	10	91.00	86.00	142.00	107.00	-60.00	100.00	94.53
9	2	500	120	15	94.00	71.00	141.00	107.00	-57.00	100.00	91.16
									Average		91.13

Table 5: The performance evaluation of Fibre Filter

Experiments	A (No of filter units)	B (Turbidity)	C (Alum Dose)	D(Settling Time)	Alkalinity Removed (%)	Electrical Conductivity Change (%)	Chromium Removed (%)	Iron Removed (%)	pH Change (%)	Mercury Removed (%)	Overall Performance
1	1	500	200	5	99.88	95.24	115.20	103.36	-53.63	98.71	91.83
2	2	2000	200	10	95.97	84.20	116.19	103.36	-51.40	100.01	89.06
3	3	2000	200	5	99.05	88.16	115.70	102.03	-51.21	98.76	89.71
4	1	500	120	15	99.43	75.47	116.19	94.72	-42.92	97.60	83.79
5	3	1500	80	5	96.79	88.58	111.57	103.36	-68.53	99.66	93.66
6	3	2000	80	15	91.09	86.25	116.19	103.36	-66.67	99.92	92.55
7	1	1500	120	10	100.03	91.78	115.20	99.90	-23.18	98.94	78.96
8	2	1500	80	10	97.17	98.05	116.19	103.36	-56.52	98.94	92.83
9	2	500	120	15	99.54	75.42	115.20	103.36	-52.70	100.01	88.21
									Average		88.96

In addition, alum as a coagulant introduced aluminium and sulphate ions, which potentially increase the ionic content of the water under treatment. Positive values of performance in EC change represent reduction in EC, experiments 7 and 8 provided the best conductivity control. In. Experiment 3 combined high turbidity, a high alum dose and a short settling time, providing the lowest performance. The lowest performance can be attributed the short settling period, which was insufficient for ionic contaminants and fine flocs to be effectively separated from water under treatment. Furthermore, the result could also be a reflection of residual sulphate ions introduced by the high alum dose, which reduce the values of EC of the water under treatment.

c. **Chromium removal: C**hromium removal using the CF treatment system was in the range of **90% to 142.20%**. The highest performance was from Experiment 4. The highest value was **142.20%**, while Experiment 3 produced the lowest performance of **90%**. Most of the experiments had performance for chromium values between 141 and 142%. In this system, chromium may be removed through: adsorption on aluminium hydroxide flocs; co-precipitation with metal hydroxides; surface complex formation; entrapment of chromium-bearing particles; and retention within the filter media. The 90% performance in Experiment 3 indicates substantial chromium removal, but it is much lower than the responses recorded in the other experiments using this system.

This result or performance suggests that the combination of three filters, turbidity of 2000 NTU, alum dose of 200 mg/l and a 5-minute settling time was comparatively unfavourable for chromium treatment. The possible explanations of this performance can be attributed to insufficient floc settling, unsuitable pH for chromium precipitation, or experimental variability in the system. Performance of the system between **141% and 142.20%** may represent a normalized performance index, analytical recovery, model-predicted response, introduction of chromium in the coagulant, or a calculation error.

d. **Iron removal:** Iron removal by this system of CF was reported as **107% in every experiment**. This uniform response or performance suggests that the tested factors had little apparent influence on iron treatment within the investigated experimental range. In the literature, iron is commonly removed by oxidation, hydroxide precipitation, coagulation, and filtration, which is expressed in equation (3). The resulting end product of iron hydroxide precipitate can be adsorbed onto alum flocs, settle out of the water, or be retained by the filter media. This type of performance (over 100%) could indicate: an instrument or method detection limit; rounding of different results to a common value; the same predicted value being assigned to all runs; a normalization procedure; introduction of iron from the coagulant used and a spreadsheet or calculation error. Because conventional removal cannot exceed 100%, the raw iron concentration data should be re-examined.

e. **pH change:** The performance of the system using CF with respect to pH change was negative in every experiment, ranging from **−18% to −73%**. The negative performance or signs indicate that the treatment system reduced pH of the water under treatment. Experiment 1 showed the smallest performance of pH reduction of**−18%**, while

Experiment 5 showed the largest performance of reduction of **−73%**. The large pH reduction in Experiment 5 is important because this experiment nevertheless had the highest overall performance. In summary, the pH decline can be explained by the hydrolysis of alum as stated in equation (4). Hydrogen ions released during this reaction or equation (4) lower the pH. In addition, alum concentration consumes alkalinity, reducing the water's ability to resist pH changes. It should be noted that excessive pH reduction can: make treated water acidic and corrosive; increase metal solubility; affect taste and acceptability; require post-treatment pH adjustment; reduce compliance with drinking-water standards. Furthermore, Experiment 1 preserved pH most effectively, but its low overall performance suggests or indicates that the overall index placed substantial weight on other parameters or may have treated a large negative pH change as a positive removal response.

f. **Mercury removal:** In the case of Mercury removal, the study reported the performance as exactly 100% in all nine experiments. This result indicates either complete mercury removal or reduction below the analytical detection limit, regardless of the operating conditions. It has been reported in the literature that possible mercury-removal mechanisms in this kind of treatment system are adsorption on alum flocs, co-precipitation, association with suspended particles, and retention by the filter media. The constant performance of 100% response suggests that mercury removal was not sensitive to the investigated factors. The result may also indicate that: the final mercury concentrations were below the detection limit; the initial concentration was sufficiently low for complete removal; the analytical method could not distinguish small differences among the treatments; and values were rounded to whole percentages.

In summary, this result suggests that multiple filtration stages improved physical retention and contaminant removal sufficiently to compensate for the low alum dose and short settling time. The condition is potentially attractive because the system or operation reduces chemical use and treatment time. Experiment 8 used two filters, medium turbidity, a low alum dose, and an intermediate settling time. The similarity suggests that different combinations of chemical dose, filtration capacity, and settling time can produce comparable overall performance. Experiment 1 had the lowest overall performance of **77.46%**. Even though it produced the highest alkalinity removal, the smallest pH change, and complete reported mercury removal. The combination of the system setup of one filter unit, an alum dose of 200 mg/l and a short settling time of 5 minutes may have caused inadequate separation of newly formed flocs. A high alum dose can produce substantial floc formation, but sufficient settling or filtration capacity is required to remove those flocs. One filter unit and a short settling period may therefore have limited the overall treatment outcome.

This result also shows that a high coagulant dose does not automatically produce superior performance. The results from Table 5 show that the treatment system using FF performed strongly in removing alkalinity and the selected metals, but the effects or performance of the system on electrical conductivity and pH varied substantially among the nine experiments. Overall performance of

the system with FF ranged between 78.96% and 93.66%, which indicates that all configurations produced some treatment benefit. The performance revealed that the operating conditions and performance in Experiments 5, 8, and 6 were the most favourable in the conditions. Experiment 5 was the best-performing treatment combination, with an overall performance of 93.66%. The experiment combined three filter units, a turbidity level of 1500 NTU, a relatively low alum dose of 80 mg/l, and a short settling time of 5 minutes. This combination is particularly important because the combination suggests that high treatment efficiency may be obtained without applying the maximum alum dose or a long settling period. The summary of individual performance can be summarised as follows:

- **Alkalinity removal:** Alkalinity removal using FF treatment system was consistently high, ranging from 91.09% to 100.03%. This indicates that the treatment process effectively reduced the acid-neutralising constituents of the water, particularly bicarbonates, carbonates and hydroxides. Experiment 7 produced the highest reported alkalinity removal of 100.03%, followed by Experiment 1 at 99.88% and Experiment 9 at 99.54%. The lowest value, 91.09%, occurred in Experiment 6. The high alkalinity reduction can be associated with alum hydrolysis.
- **Electrical conductivity change:** Electrical conductivity change using FF treatment system ranged from 75.42% to 98.05%. Experiment 8 produced the greatest change at 98.05%, followed by Experiment 1 at 95.24% and Experiment 7 at 91.78%. The lowest values were obtained in Experiments 9 and 4, at 75.42% and 75.47%, respectively.
- **Chromium removal:** Chromium removal using FF treatment system was reported to be between 111.57% and 116.19%. The maximum value of 116.19% occurred in Experiments 2, 4, 6 and 8, while the lowest value of 111.57% occurred in Experiment 5. The consistently high values show that the system had a strong affinity for chromium.
- **Iron removal:** Iron removal using FF treatment system ranged from 94.72% to 103.36%. Experiment 4 gave the lowest value, while Experiments 1, 2, 5, 6, 8 and 9 gave the highest reported value of **103.36%**. The strong iron removal can be explained by oxidation and precipitation of dissolved iron as insoluble iron hydroxides, followed by coagulation and filtration.
- **pH change:** The pH change response using FF treatment system was negative in every experiment, ranging from −68.53% to −23.18%. This indicates that the treatment caused a reduction in pH, although percentage change is not generally the best way to express pH because pH is logarithmic. Experiment 7 showed the smallest pH change at −23.18%, meaning it preserved the initial pH better than the other conditions. Experiment 5 produced the largest change at −68.53%, followed by Experiment 6 at −66.67%. The pH reduction is consistent with the hydrolysis of alum.
- **Mercury removal:** Mercury removal using the FF treatment system was highly effective and remarkably stable,

ranging from 97.60% to 100.01%. The highest value, 100.01%, occurred in Experiments 2 and 9, while the lowest value, 97.60%, occurred in Experiment 4. Possible mercury-removal mechanisms include adsorption onto freshly formed aluminium hydroxide flocs, association with suspended particles, co-precipitation and retention within the filter media. The relatively narrow range indicates that mercury removal was less sensitive to changes in filter number, turbidity, alum dose and settling time than electrical conductivity or pH.

In general, **e**xperiment 5 using the FF treatment system achieved the highest overall performance of **93.66%** under the following conditions: three filter units; turbidity of 1500 NTU; alum dose of 80 mg/l; settling time of 5 minutes. It produced high alkalinity removal (96.79%), conductivity change (88.58%), iron removal (103.36%) and mercury removal (99.66%). Chromium removal in this experiment was the lowest in the dataset, although still reported as 111.57%. The main disadvantage of this setup was the very large negative pH change of –68.53%. The high overall score obtained at the lowest alum dose suggests that treatment performance was not controlled by alum dosage alone. The three filter units probably provided greater media depth, surface area, and contaminant-retention capacity.

The result also suggests potential savings in chemical consumption and settling time. Experiment 8 recorded the second-highest overall performance of 92.83% using two filter units, turbidity of 1500NTU, an alum dose of 80 mg/l and a settling time of 10 minutes. The experiment produced the highest electrical conductivity response (98.05%), maximum reported chromium removal (116.19%), high iron removal (103.36%), and nearly complete mercury removal (98.94%). Experiment 8 may represent a more balanced treatment option because the experiment required fewer filter units than Experiment 5 while achieving only a slightly lower overall performance. Experiment 6 achieved an overall performance of 92.55% at the highest turbidity of 2000NTU, using three filter units, 80 mg/l of alum dose and 15 minutes of settling.

This performance demonstrates that the system can maintain high performance under heavily turbid conditions. The experiment produced the lowest alkalinity removal (91.09%) and a substantial pH decrease of –66.67%. Experiment 7 produced the lowest overall score of 78.96%, despite having the highest reported alkalinity removal and the smallest pH decrease. This performance suggests that the overall performance calculation may penalize or transform the pH response differently from the other variables. The relatively low-performance score also indicates that excellent performance for one parameter does not necessarily produce the best multi-response treatment. In addition, the apparent influence of these selected operating factors on the performance of the three filtration techniques can be summarised as follows

- **Number of filter units:** Three-filter configurations generally performed well, particularly Experiments 5 and 6. Additional units probably increased contact area, media depth and contaminant retention.
- **Turbidity:** High initial turbidity did not prevent effective treatment.

Experiment 6 performed strongly at a turbidity of 2000 NTU, indicating that coagulation and filtration remained effective at high particle loading.

- **Alum dose:** The 80 mg/l-unit dose produced the three highest overall performances. This performance suggests that excessive alum addition was unnecessary and might have increased acidity or residual dissolved ions.
- **Settling time:** The best result or performance was obtained after only 5 minutes. Longer settling times did not consistently improve performance, implying that floc formation and contaminant capture may have occurred rapidly.

Overall, the three media responded differently to changes in operating conditions (Table 6). Ceramic filtration produced the highest average performance. Fibre filtration was the most consistent across the experiments. Activated carbon achieved the highest single performance but was the most sensitive to operating conditions. Ceramic filtration exceeded fibre filtration by approximately 2.17 percentage points and activated carbon by 7.65 percentage points. The average values alone do not identify the best practical system because cost, consistency, required chemical dose and performance under high turbidity must also be considered. Experiment 7 had the highest combined mean performance of 90.78%, followed closely by Experiment 2 at 90.69%. In addition, Experiment 2 was much more balanced across the three filter types, with performances ranging only from 89.06% to 92.91%.

The analysis is a two-factor ANOVA comparing the nine experimental operating conditions and the three filter types fibre, ceramic, and activated carbon is presented in Table 7. The Table revealed that the experiments produced different numerical performances; the differences were small relative to the unexplained variability in the dataset. Some particular conditions appeared descriptively better for particular filters, but ANOVA indicates that these differences could reasonably have arisen from experimental variation or filter-specific responses. The very high p-value of 0.9748 ($F_{8,16}$ = 0.246 and p = 0.975) provides little evidence that filter number, turbidity, alum dose, and settling time as combined in the nine runs produced different overall mean performances when averaged across the filter media. This does not prove that all operating conditions are exactly equivalent. The result means that the present experiment did not provide sufficient statistical evidence to demonstrate a difference ($F_{2,16}$ = 1.999 and p = 0.168).

The experimental mean square was substantially smaller than the error mean square. This indicates that differences among the nine experiments were very small compared with the residual variation. The filter mean square was approximately twice the error mean square, suggesting a potentially larger filter effect. The result was still below the critical threshold needed to demonstrate statistical significance. The implication of all these is that at the conventional significance level of 95 %, the analysis found no statistically significant difference among the nine experiments and no statistically significant difference among the three filter types.

Figure 8 shows the results of SEM and EDS of the coagulant used. The results revealed that the coagulant contained some metals and other impurities such as Al, Fe, Si, Mg and Hg. These results explained some of the factors for more than 100 % due to the presence of Hg and negative performance due to the presence of Si, Mg, and Ca that are either metalloids or alkali earth metals, respectively.

Table 6: The performance evaluation of overall performance of all the filters

Experiments	A (No of filter units)	B (Turbidity)	C (Alum Dose)	D (Settling Time)	Fibre Filter	Ceramic Filter	Activated Carbon	Best Medium
1	1	500	200	5	91.83	77.46	91.69	FF
2	2	2000	200	10	89.06	92.91	90.09	CF
3	3	2000	200	5	89.71	85.71	79.21	FF
4	1	500	120	15	83.79	94.58	89.86	CF
5	3	1500	80	5	93.66	97.29	75.66	CFc
6	3	2000	80	15	92.55	91.42	67.57	FF
7	1	1500	120	10	78.96	95.13	98.26	ACF
8	2	1500	80	10	92.83	94.53	75.12	CF
9	2	500	120	15	88.21	91.16	83.90	CF

Table 7: Analysis of Variance of overall performance of the selected filters

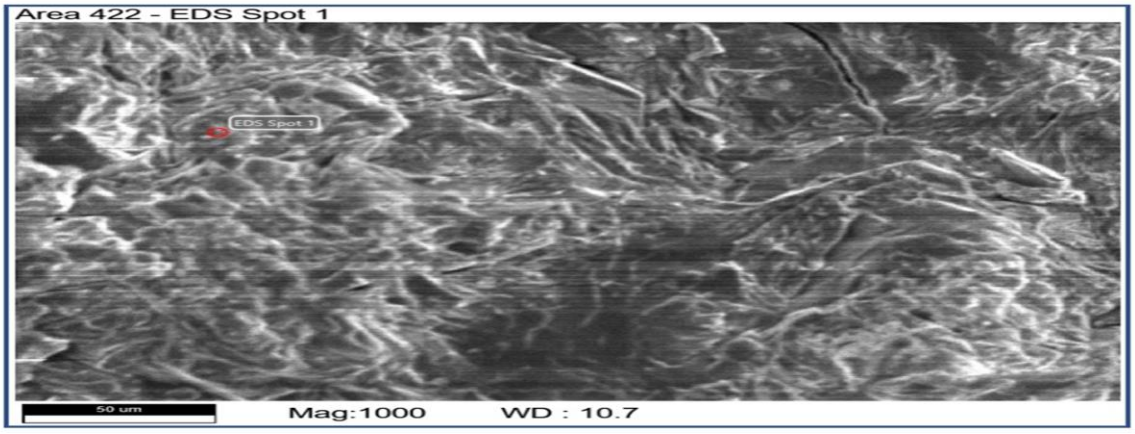
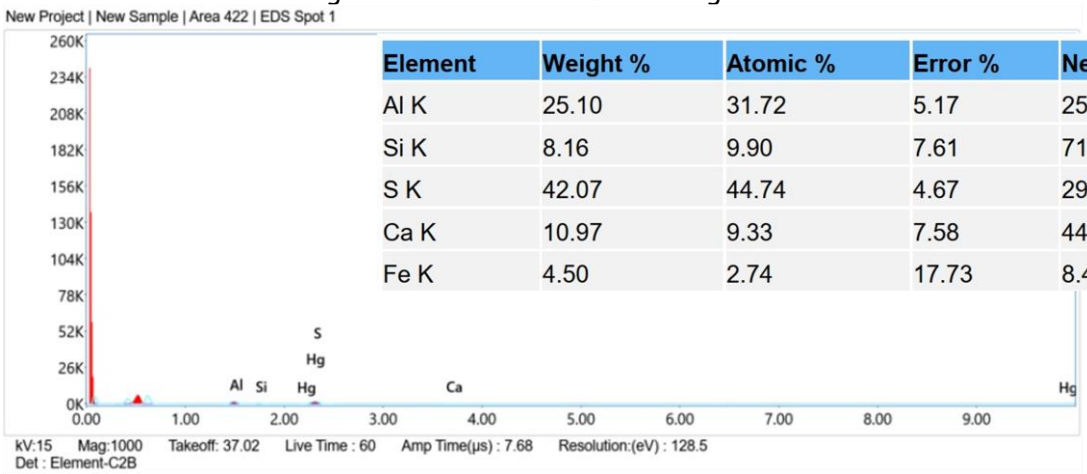


Figure 8a SEM result of the Coagulant



Element	Weight %	Atomic %	Error %	Net Int.
Al K	25.10	31.72	5.17	254.80
Si K	8.16	9.90	7.61	71.42
S K	42.07	44.74	4.67	298.51
Ca K	10.97	9.33	7.58	44.57
Fe K	4.50	2.74	17.73	8.42

Figure 8b: EDS result of the coagulant

Source of Variation	Sum of Square	Degree of freedom	Mean Square	F-value	P-value	F crit
Between the Experiments	137.5973461	8	17.19967	0.246119	0.97476	2.591096
Within the Filters	279.4062983	2	139.7031	1.999088	0.167895	3.633723
Error	1118.135303	16	69.88346			
Total	1535.138947	26				

CONCLUSION

Based on the findings, it can be concluded that:

- Ceramic filtration demonstrated the best overall performance, with an average of 91.13%, and was the leading medium in five of the nine experiments.
- Fibre filtration recorded an average of 88.96% and was the most consistent medium, making it potentially suitable for variable raw-water conditions.
- Activated carbon had the lowest average of 83.48%, but it produced the highest individual performance of 98.26% under the optimized conditions of Experiment 7.
- Experiment 5 was optimal for fibre and ceramic filtration, giving 93.66% and 97.29%, respectively, with three units, turbidity of 1500 NTU, alum dose of 80 mg/l and 5 minutes of settling.
- Experiment 7 was optimal for activated carbon, giving 98.26% with one unit, turbidity of 1500NTU, alum dose of 120 mg/l and 10 minutes of settling.
- For a treatment system requiring reliable performance across all three media, Experiment 2 represents the most balanced condition.
- For maximum mean performance, Experiment 7 was marginally superior. These results demonstrate that filter-media selection and operating-condition optimization should be carried out together because each filter responds differently to alum dose, turbidity, and settling time.
- These treatment systems showed strong potential for improving water quality, especially for alkalinity, iron and mercury removal.
- The optimum observed treatment was Experiment 5, with three filter units, turbidity of 1500NTU, alum dose of 80 mg/l and settling time of 5 minutes, producing an overall performance of 97.29%. This combination demonstrates that high efficiency can be obtained with a relatively low alum dose and short settling time when sufficient filtration capacity is available.
- Experiment 7 may be a practical and potentially cheaper alternative because it achieved 95.13% performance using only one filter unit. But Experiment 5 produced a substantial reduction in pH, meaning that post-treatment pH correction may be necessary. The experimental system demonstrated strong alkalinity and metal-treatment performance.
- The performance of household water filters is governed by the interaction between filter characteristics and

operating conditions. Fibre filters are effective pretreatment devices, ceramic filters provide strong fine-particle and microbial removal, and activated carbon improves dissolved-organic and aesthetic quality.

- The optimum values of these selected factors (influent turbidity, number of filters, treatment time, and coagulant dose) were 1080 NTU, 2, 12.8 minutes, and 135 mg/l.
- Understanding these selected factors is essential for optimizing treatment performance, improving public health outcomes, and enhancing the sustainability of household water treatment interventions.

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