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Efficiency of Ceramic Candle Filters towards Purification of Drinking Water

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Abstract

This study addresses a critical research gap in Nepal, focusing on the effectiveness of ceramic candle filters for purifying drinking water. The research assesses their performance in removing physico-chemical and microbiological parameters, along with flow rates. A market survey in Kathmandu and Surkhet informed the selection of five brands. A cross-sectional, block design experiment over two cycles measured water quality and flow rates. Physico-chemical parameters met NDWQS standards. Microbial tests revealed a significant reduction in *E. coli* and total coliform bacteria, albeit not within NDWQS limits. Flow rates showed no significant variations. Comparative analysis favored silver-coated (CS) filters, with Apollo among non-CS filters exhibiting the highest microbiological efficiency, followed by Hotsun, Surya Vinayak, Surya Nepal, and Milton. This research aims to contribute valuable insights for promoting efficient point-of-use water treatment practices in Nepal.

Key words: *Colloidal silver (CS), NDWQS, point-of-use water treatment, water borne diseases*

Introduction

Safe drinking water and basic sanitation are fundamental human needs. Despite this, approximately two billion people worldwide lack access to clean and safe drinking water, and about 3.6 billion people lack adequate sanitation services (UN, 2023). Drinking contaminated water is the leading cause of various diseases, including infectious hepatitis, cholera, bacillary dysentery, typhoid, paratyphoid, salmonellosis, colibacillosis, giardiasis, cryptosporidiosis, and amoebiasis (Pal et al., 2018).

The absence of safe drinking water and sanitation, particularly in developing countries, results in approximately half the population suffering from one or more of the six main water-related diseases (Diarrhoea, Ascariasis, Dracunculiasis, Hookworm, Schistosomiasis, and Trachoma). Tragically, about 400 children under the age of five die per hour in the developing world from waterborne diarrheal diseases (WHO, 1996; 2017). Annually, around 4 billion cases of diarrhea occur, causing 1.8 million deaths, with 90% of these deaths occurring in children under the age of five in developing countries (UNICEF, 2008).

Despite having abundant fresh water resources in the Indian subcontinent, issues arise from spatial and temporal discrepancies in distribution (Subramanian, 2004). Industrial growth, unplanned urbanization, and population growth contribute to water pollution in developing countries (Cohen, 2006). Poor sanitation and contaminated drinking water, resulting from both human activity and natural phenomena, pose serious health problems (Pandey, 2006).

Nepal has made significant strides in child health, yet child mortality remains high, with diarrhea as the leading cause (WHO, 2018). The Nepalese population primarily relies on three water sources: surface water, ground water, and municipal supplied piped water. In rural areas, especially in the central and northern parts of the country, people predominantly use surface water such as springs and streams, where water quality varies with seasons

(Sagara, 2000). Bacteriological contamination is the primary concern for drinking water in mountainous regions like Kathmandu valley (Rai et al., 2009; Warner et al., 2008).

Intermittent water supply systems increase the risk of microbial contamination (Kumpel & Nelson, 2013). Water-related disease outbreaks are common in the western part of Nepal (Bhandari & Bhusal, 2013; Bhandari et al., 2009). Limited resources hinder Nepal from investing in large centralized projects, leading to pollution of surface and ground water through sewage, domestic waste, and industrial and agricultural effluents, impacting the health of all life forms (Hunter et al., 2009).

Household water treatment and safe storage technologies (HWTS) play a crucial role in providing safe drinking water, serving as an additional barrier against waterborne diseases (Dore, 2015). Various HWTS, including chlorination, combined coagulant-chlorine disinfection, SODIS, ceramic filters, and bio-sand filters, are commonly used in developing countries (Sobsey et al., 2008). The selection of HWTS depends on factors such as cost-effectiveness, people's willingness, availability, and ease of use. Ceramic water filters stand out as an easy, convenient, and effective means of treating water at the household level, particularly in developing countries like Nepal (Clasen et al., 2004; Clasen et al., 2006; Johnson et al., 2015; Lamichhane and Kansakar 2013; Sobsey et al., 2008). Despite the high affordability, willingness to pay, and usage of ceramic candle filters in different districts of Nepal (ENPHO, 2013), there is a lack of comparative studies assessing the efficiency and effectiveness of filter candles available in the Nepalese market under different brand names. This study aims to fill that gap by assessing the performance of different ceramic filter candles available in the Nepalese market.

Materials and Methods

Study Area

The survey sites for this study were purposefully selected to include Kathmandu Valley and Surkhet district in Nepal. Kathmandu Valley, situated in the mountain region, encompasses three major districts:

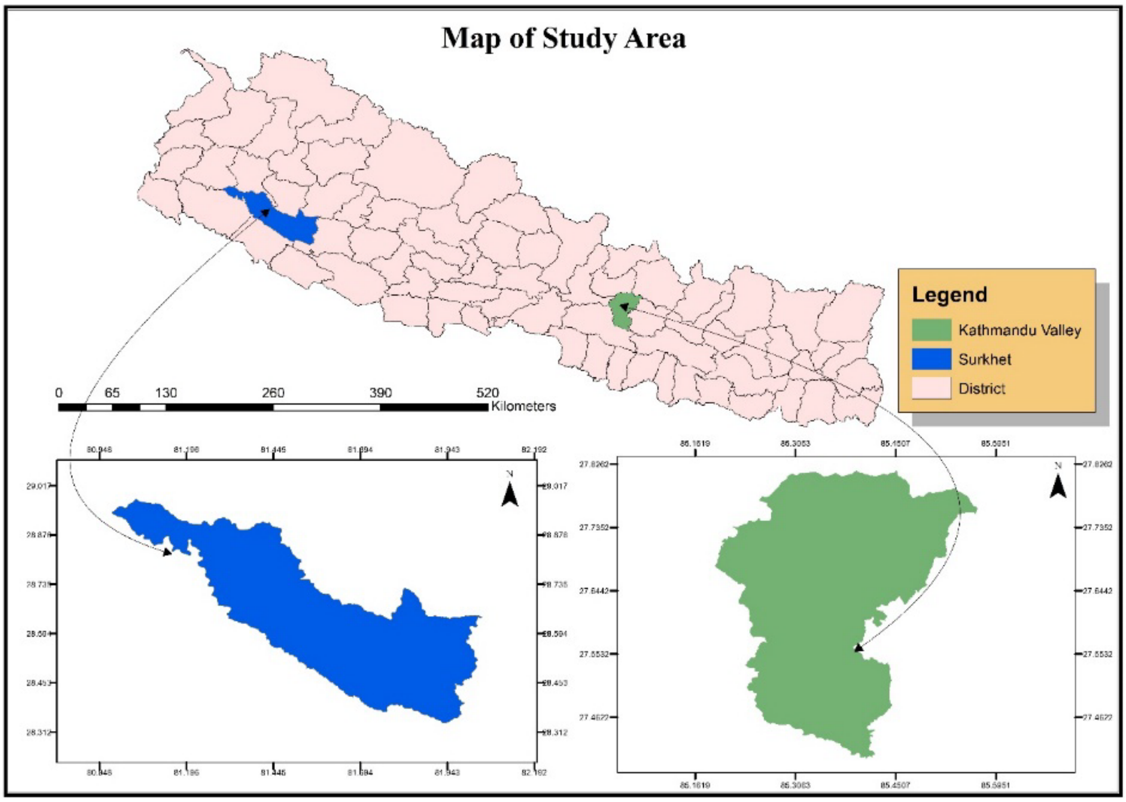

Figure 1: Study area map featuring Kathmandu and Surkhet districts, showcasing the sampling sites for commonly used filter models

Kathmandu, Lalitpur, and Bhaktapur. Serving as the capital city, it functions as a central hub for politics and the economy, located in the central development region of Nepal. On the other hand, Surkhet is one of the 77 districts of Nepal, situated in the mid-western development region. It is surrounded by Dailekh, Jajarkot, Salyan, and Bardia in the mid-western development region, as well as Kailali, Doti, and Achham in the far-western development region, areas known for a high occurrence of waterborne epidemics.

Design of Experiment

To initiate the study, a survey of ceramic candle filters available in the market was conducted, leading to the selection of the top five brands based on interviewee preferences and cost-effectiveness. The experimental design adopted a cross-sectional, block structure to fulfill the study's objectives. The entire experiment unfolded over two cycles, each spanning 14 days, encompassing three replicates for each selected filter brand.

Before installation, all ceramic candles underwent a 24-hour soaking in plain water. Subsequently, they were meticulously cleaned under running water, eliminating any attached ceramic materials. The cleaned candles were then fitted into serialized stainless-steel housing. In the first cycle, the experiment utilized high-turbidity well water (> 5 NTU) as the raw water (acting as a challenge). Following the completion of the first cycle, all ceramic candles were removed and delicately cleaned using a soft nylon brush under running water.

Moving to the second cycle, low-turbidity reserve tank water (< 5 NTU) was employed, mirroring the predominantly clear and low-turbidity water commonly used as raw water in households. In this phase, two additional silver-coated filter brands, namely Madhyapur Clay Crafts (MCC) – a locally produced filter brand – and Tripti (promoted by SMART PANI in the private sector), were introduced, each with three replicates. This expansion aimed to broaden the scope of the study and assess the performance of these additional filter brands.

Figure 2: A photograph showcasing the filter setup for experimentation. Initially, 15 filters from five brands were utilized. In the second phase, two additional brands were incorporated, bringing the total to 21 filters from seven brands.

Analytical Procedures

Table 1: Details of the methodology used to assess each parameter

SN	Parameters	Unit	Description
1	Flow Rate	Water Yielded (in L)/Candle	Measurements were conducted for two types of water, i.e., > 5 NTU turbidity and < 5 NTU, respectively. The water collected after a five-hour period was measured to calculate the flow rate, which was then converted into flow rate per candle. We adjusted the usual 12-hour sampling period, commonly used (Annan et al., 2014), to ensure that the quantity corresponds to the amount generated in a single sitting.
2	pH		Potentiometric Method (APHA, 2012) – using the calibrated pH meter whose electrode was calibrated using standard buffer solution ((pH 4, pH 7 and pH 9.2)
3	Turbidity	NTU	Measured using Nephelometric method (APHA, 2012) by a Hach 2100P portable turbidimeter.
4	Iron Content	mg/L	Measured using Atomic Absorption Spectrometric method (APHA, 2012) by Atomic Absorption Spectrometer, ICE 3000 SERIES, Thermo-Scientific.
5	Total coliform and *E. coli*	Numbers of "colony forming units" (CFU) per 100 ml of original sample	Membrane Filtration Technique (MF) was used for assessment of microbial density in the water sample (APHA, 2012).

Data Analysis

The mean of different parameters (from three replicates of each filter brands) were calculated to compare with the National Drinking Water Quality Standards (NDWQS, 2005) for each day.

Microbiological quality of raw and treated water was compared to qualitative multi risk level (Reygadas et al., 2015) as presented in Table 2.

Table 2: Bacteriological Risk Level based on Reygadas et al. (2015)

CFU/100mL	Risk Level
0	No risk (NR)
1-10	Low risk (LR)
10-100	Intermediate risk (IR)
100-1000	High risk (HR)
>1000	Very high risk (VHR)

Quality Control

The experiment and lab analysis were conducted under sterile conditions to minimize microbial contamination, utilizing analytical-grade chemicals and apparatus. Prior to each cycle, the filters underwent sterilization with 95% ethanol. Autoclaved sampling bottles were employed for microbial parameter analysis, while clean bottles with preservatives were used for iron content sampling. Additionally, clean sampling bottles were utilized for other parameters. To ensure accuracy and precision, a sample blank was included on each sampling day. Water quality analysis for each parameter included intermittent introduction of a blank and a standard after every 8 samples.

Results and discussion

Parameters

Flow Rate: Flow rates for all Ceramic candle filter brands were tested across two cycles, consistently showing higher rates in the second cycle (Figure 3). This difference is attributed to the higher turbidity in the water samples used during the first cycle, leading to clogged pores in the ceramic candles and subsequently lower flow rates. Notably, the MCC brand exhibited the highest initial flow rate, followed by Tripti, while the Apollo brand demonstrated an overall lower flow rate. Porosity plays a key role in filtration capacity, influencing flow rates positively (Mellor et al., 2013).

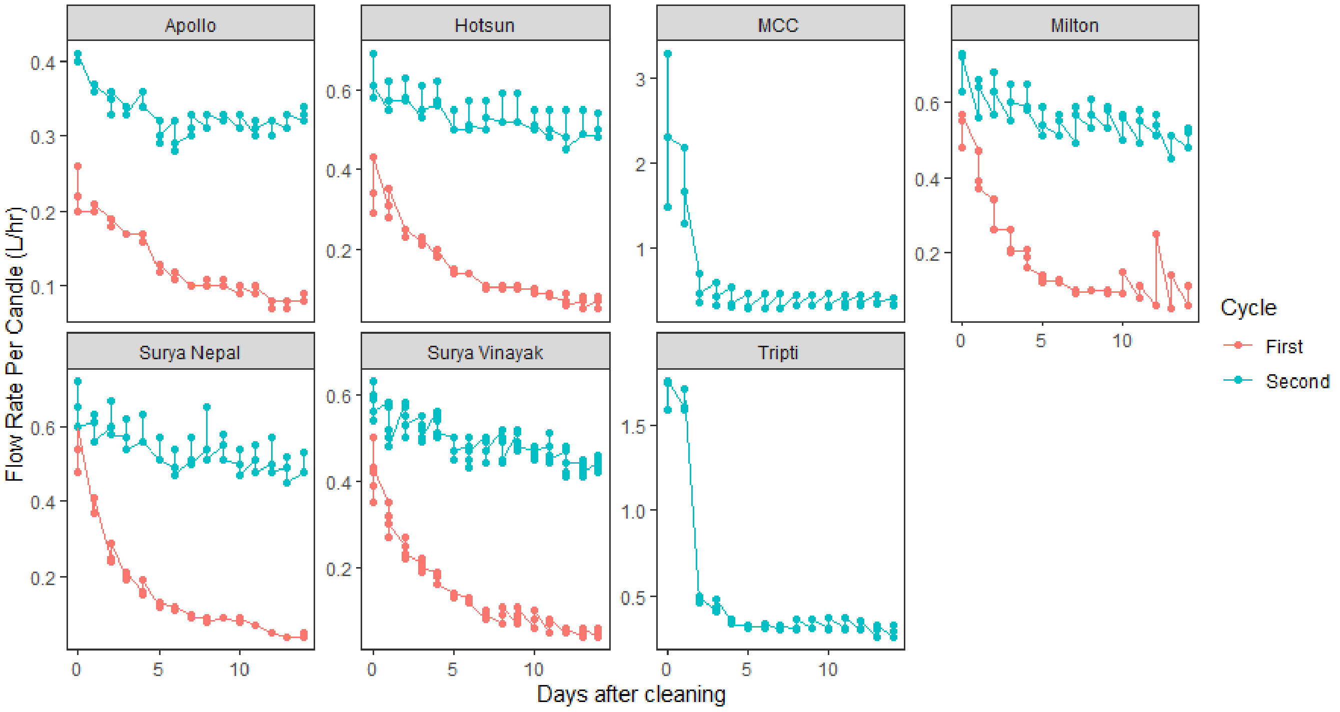

Figure 3: Comparison of flow rates among various candle brands in the first and second cycles. MCC and Tripti brand filters were introduced exclusively in the second cycle. Additionally, the y-axis has been plotted on a free scale for better visualization

pH: Comparison of pH values revealed that the filtered water exhibited a consistently higher pH than the raw water. The treated water's pH ranged from 7.3 to 8.5, while the raw water's pH ranged from 6.73 to 7.97. Although the pH of the treated water in the second cycle complied with NDWQS limits, the first cycle's pH exceeded the permissible range. This discrepancy may be attributed to the ceramic material's alkaline components, such as calcium carbonate (Mellor et al., 2013). Additionally, the leaching of minerals like alumina or zeolites in some ceramic filters can impact water pH (Sobsey et al., 2008). The buffering action of the ceramic filter may have contributed to the slight pH increase in the filtered water (Mellor et al., 2013). However, we did not assess the chemical composition of the ceramic filter to state with confidence.

Turbidity: In the first cycle, raw water with turbidity ranging from 5 to 25 NTU was used, while in the second cycle, water with turbidity below 5 NTU was employed. All filter brands efficiently removed turbidity in both cycles, consistently meeting the NDWQS limit (>5 NTU), except on the seventh day of the first cycle when an anomaly occurred. Although all filter brands showed higher turbidity than the NDWQS limit on that day, the levels remained lower compared to the raw water (Figure 5). This aligns with findings by Sagara (2000), who observed similar turbidity removal in a study on point-of-use drinking water treatment in Nepal. Laboratory experiments suggest that candle filters are highly effective in removing

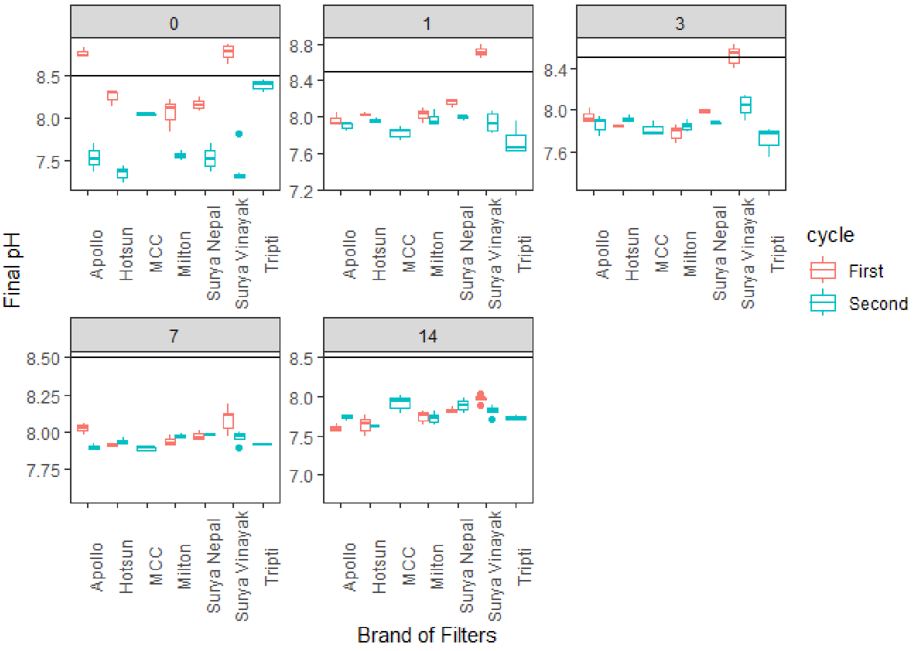

Figure 4: Final pH of Water Sample after filtering. The number on the heading (top of each box) represents the days after cleaning the filter, and the colors represent the cycles.

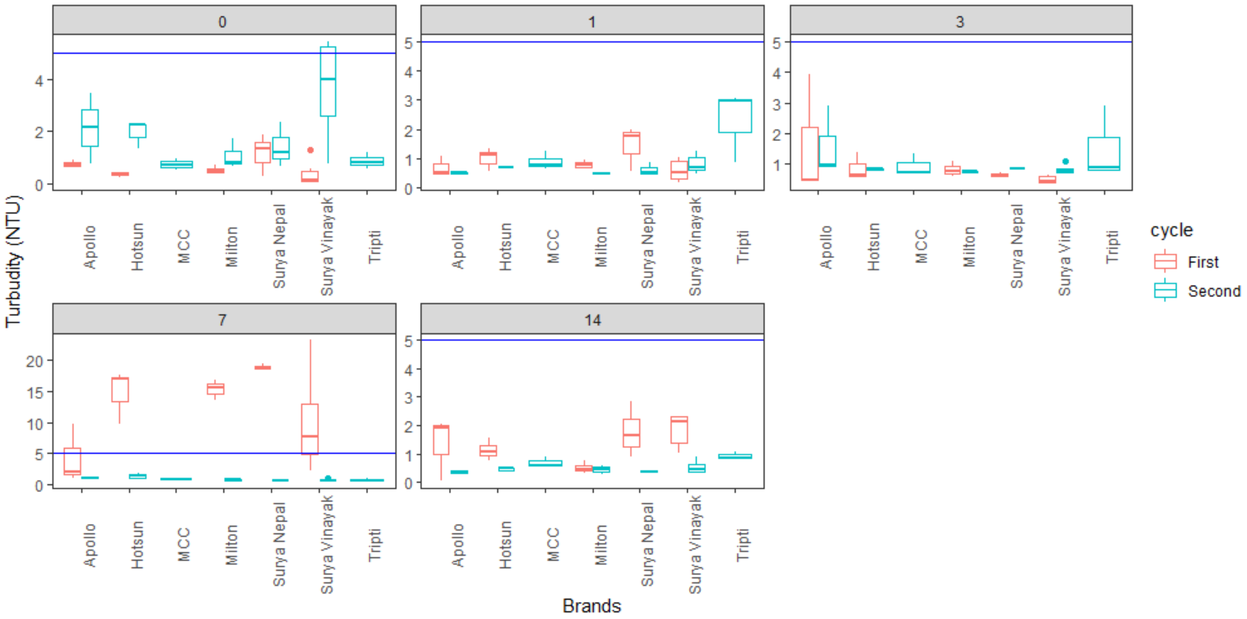

Figure 5: Turbidity of water sample (the scale along y axis is in free scales).

turbidity, achieving 100% removal, and are also capable of removing pathogens due to their pore size being less than 40 nm (Suribabu et al., 2020). The results indicate significant turbidity removal by filter systems, achieving levels less than 1 NTU. The efficiency of candles increases as the days pass by since the pores get clogged and filtration becomes even slower (Sagara, 2000).

Iron content: All studied filter brands demonstrated effective removal of iron content from raw water in both cycles when water with iron content ranging from greater than 0.3 mg/l up to 3.5 mg/l was used. However, an exception occurred on the seventh day of the first cycle when the treated water exceeded the NDWQS limit of the maximum concentration of 0.3 mg/l, as illustrated in Figure 6 below. This anomaly might be due to the fact that the raw water samples used on that day for the first phase contained unusually higher level of pollutions along with its dissolved iron, which we can also observe in the figure. In addition, candle filters don't have 100% iron removal efficiency (Zereffa & Bekalo, 2017; Bulta & Micheal, 2019), as iron in dissolved (ferrous) form may pass through the filter unless it is precipitated. The primary mechanism for iron removal is aeration, wherein the aeration of water leads to the oxidation of ferrous iron by oxygen, resulting in the formation of precipitation (Mazzei, 2011).

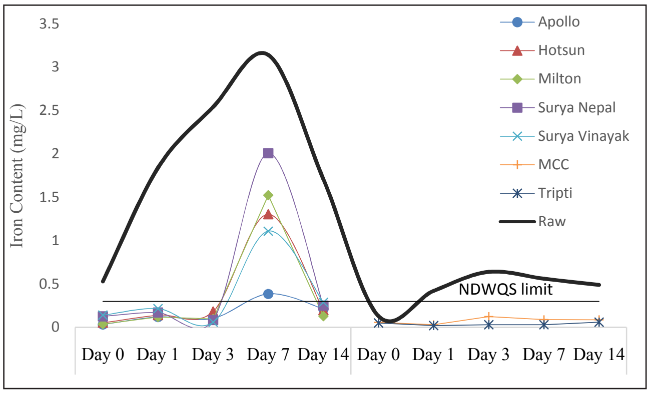

Figure 6: Iron content in raw and filtered water.

Total Coliforms and *E. coli:* All studied ceramic filter brands significantly reduced total coliforms and *E. coli* in filtered water compared to raw water. However, in most cases, the filtered samples exceeded the NDWQS limit for microbial parameters (Figure 7 and Figure 8). In the first cycle, where raw water had very high levels of total coliforms and *E. coli*, reductions in total coliforms were within the Very High Risk (VHR) level. For Apollo, most samples exhibited an intermediate risk level for *E. coli*, while all samples from Milton fell into the high-risk level zone. In the second cycle, with low turbid water as raw water, bacteriological load was lower than in the first cycle. As raw water microbial concentration decreased, total coliform and *E. coli* concentrations ranged from High Risk (HR) level to Low Risk (LR) level.

By the end of the second cycle, when bacteriological concentration in raw water was in the high-risk level range, most filter brands reduced total coliform and *E. coli* to Low Risk to No Risk levels. Calculating the average microbial log reduction for different brands revealed that MCC achieved the maximum log removal for both bacteriological parameters, while Surya Nepal showed the minimum reduction. Among non-silver-coated filters, Apollo exhibited the highest reduction for both bacteriological parameters (Table 3).

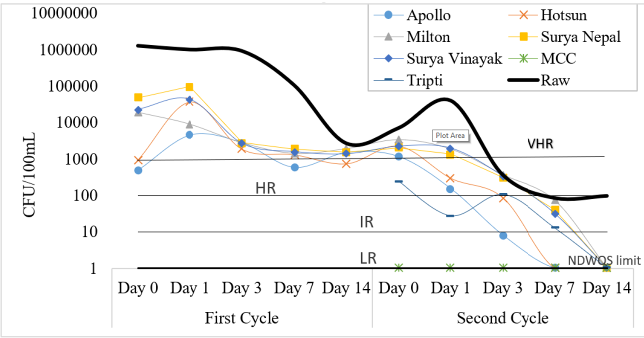

Figure 7: Total coliform in raw and filtered water. (VHR – very high risk, HR- High Risk, IR – Intermediate Risk, and LR- Low Risk)

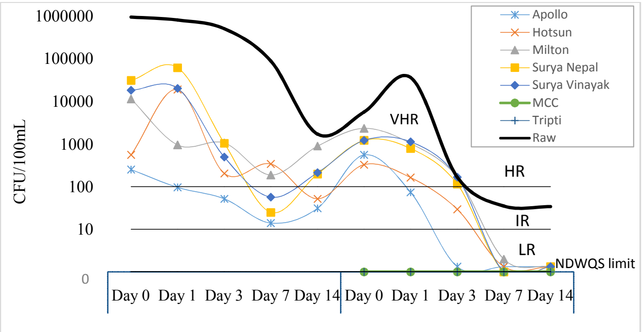

Figure 8: *E. coli* in raw and filtered water (VHR – very high risk, HR- High Risk, IR – Intermediate Risk, and LR- Low Risk)

Table 3: Average log reduction of total coliform and E. coli

Brands	Log reduction in Total coliform removal	Log reduction in *E. coli* removal
Apollo	2.01	2.64
Hotsun	1.79	2.22
Milton	1.33	1.66
Surya Nepal	1.26	1.65
Surya Vinayak	1.34	1.80
Madhyapur Clay Craft	2.99	2.72
Tripti	2.33	2.72

Conclusion

The markets in Kathmandu and Surkhet feature various non-silver-coated (non-CS) filters, with some organizations independently producing and promoting silver-coated (CS) filters. Regarding the enhancement of physio-chemical parameters in treated water compared to raw water, ceramic candle filters prove effective in efficiently reducing turbidity and iron content below the maximum NDWQS limit. However, challenges arise in rare conditions, particularly when raw water exhibits high turbidity and iron content.

In terms of microbial removal, both CS and non-CS filter brands exhibit significant reductions in microbial concentration but often fall short of meeting the NDWQS requirement of 0 CFU/100mL for E. coli and total coliform. Yet, when microbial concentration is relatively low, below 100 CFU per 100mL, silver-coated ceramic candle filters demonstrate complete removal of microbial contaminants. The anti-bacterial properties of silver in CS filters, in addition to potential blockage prevention, contribute to the thorough elimination of total coliforms and E. coli in treated water.

Flow rates for all filter brands were consistently less than one liter per hour per candle in most cases. Flow rates are dependent on the turbidity of raw water, as higher turbidity leads to pore blockage in candles, causing reduced flow rates. The use of low turbidity water is crucial to achieving maximum and consistent water volume, reducing cleaning intervals, and enhancing the durability of candles.

Data Availability Statement

The data presented in this study are available upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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ANNEXES

ANNEX-I: Available filter brands, frequency and price

Thirteen brands of ceramic candle filters were identified through a purposive questionnaire survey in major markets in Surkhet and Kathmandu Valley. Five of the most commonly available and cost-effective brands—Apollo, Hotsun, Milton, Surya Nepal, and Surya Vinayak—were selected for the efficiency study (Table 4).

Table 4: Frequency and price of available ceramic candle filters in Kathmandu and Surkhet

	No of Shops			Price (NRs)		
Filter Brands	Kathmandu	Surkhet	Total	Min	Max	Mean
Surya Vinayak	4	15	19	1050	1450	1129
Milton	10	7	17	1050	1660	1321
Surya Nepal	5	6	11	1050	1350	1164
Apollo	4	1	5	1050	1400	1263
Hotsun	0	1	1	1100	1100	1100
Famous Nepal	5	0	5	1100	1350	1230
Puro	2	0	2	1900	2100	2000
Natural	1	0	1	1300	1300	1300
Perfect	2	0	2	2450	2800	2625
Youwe	2	0	2	2600	2800	2700
Maharaja	0	3	3	6000	6000	6000
Saga	0	1	1	6080	6080	6080
Tulip	0	1	1	1050	1050	1050

ANNEX-II: Efficiency of microbes, turbidity and iron removal

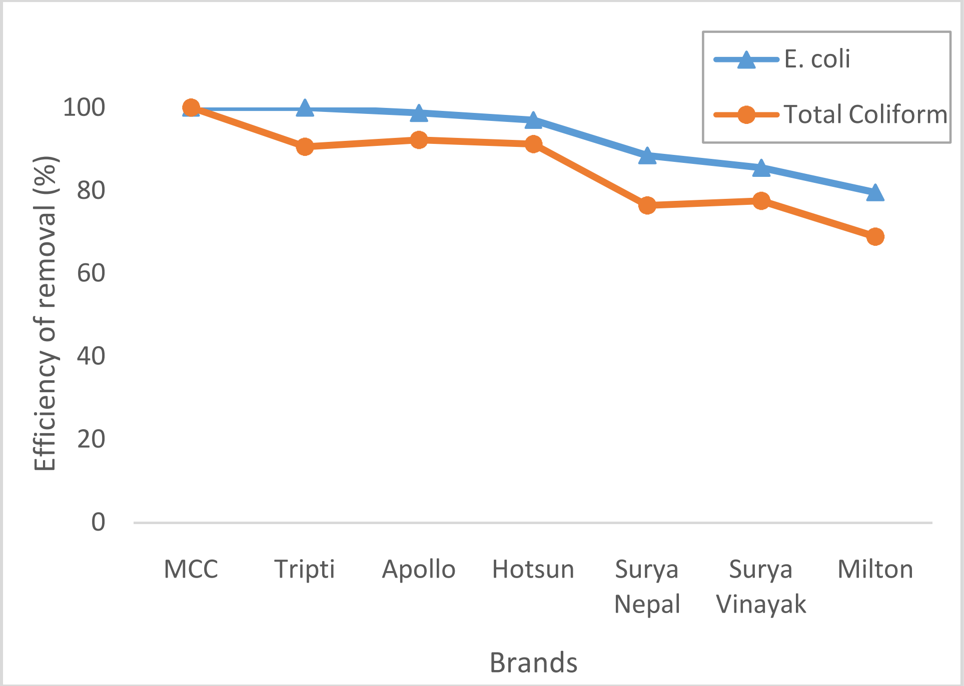

Figure 9: Efficiency of microbial removal

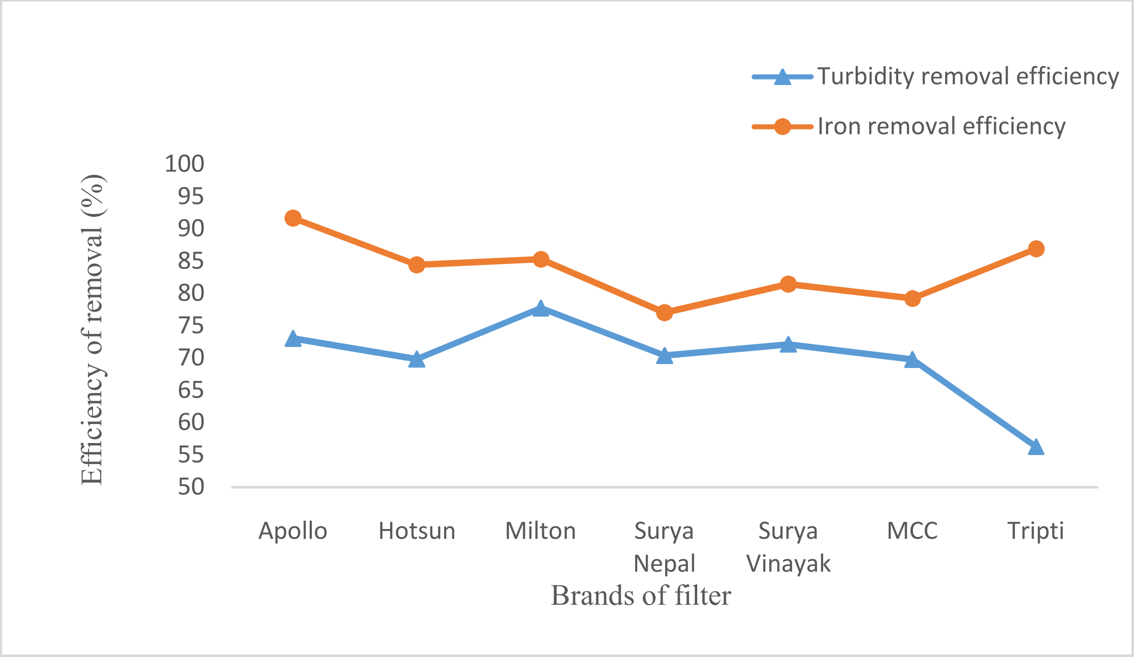

Figure 10: Efficiency of iron and turbidity removal

ANNEX-III: Relationship between iron content and turbidity in the filtered water

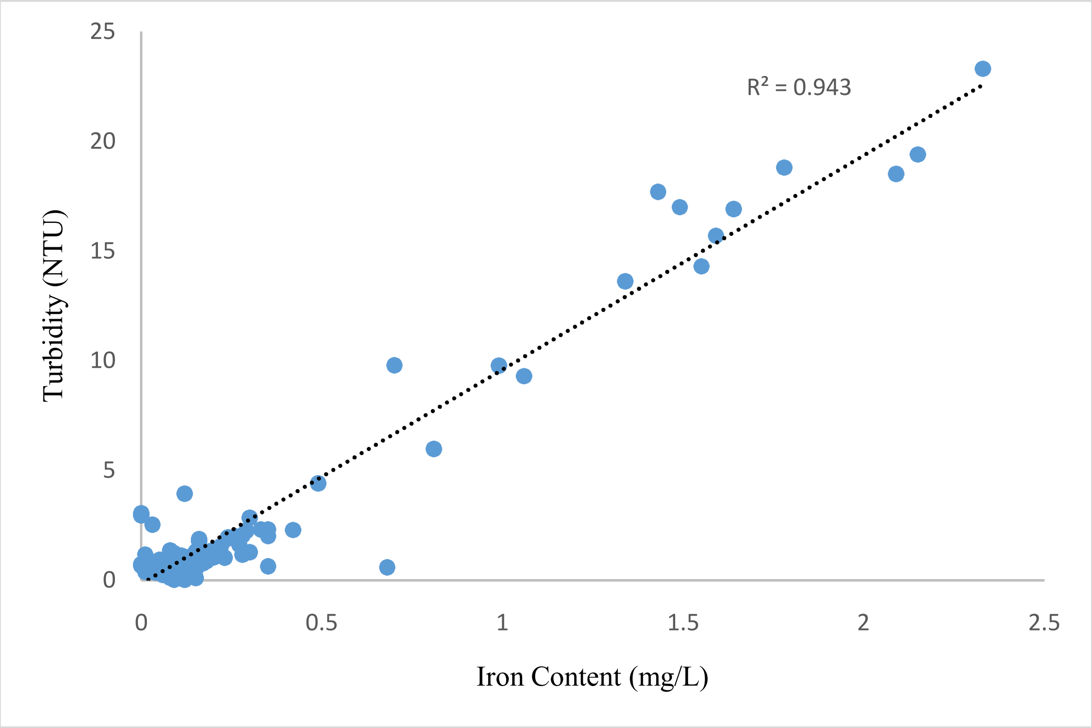

Figure 11: Relation between turbidity and iron content in filtered water