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Long-term evaluation of the performance of four point-of-use water filters

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ABSTRACT

Despite technological advances water supply quality and poor access to safe water remain a major problem in developing countries, especially in rural areas. Point-of-use (POU) water treatment has been shown to be a viable option to produce safe drinking water quality. The aim of this study was to evaluate, under laboratory conditions over 14 months, the performance of four household filtration systems: membrane filter (MF), one-candle ceramic filter (1CCF), two-candle ceramic filter (2CCF) and pot ceramic filter (PCF). The evaluation was made using spiked water having the required concentrations of turbidity, *Escherichia coli* and Total Dissolved Solids (TDS). The results show that all systems have high removal efficiencies for turbidity (98–99%), and *E. coli* 4–5 Log Reduction Value (LRV). The poorest efficiency was for TDS (9–18%). The MF and the CCF displayed no significant difference in efficiencies for these parameters. The PCF had less significant differences for turbidity removal than the other systems. The average filtration rate for all systems decreased during the operation time. The CPF showed the major potential to be used in rural communities mainly for its low operational level and maintenance requirements as well as its local craftsmanship. It was observed that the efficiency of the systems is highly sensitive to cleaning and maintenance activities and therefore, the system sustainability will depend considerably on the training and education of the potential users.

1. Introduction

The World Health Organization (WHO) and UNICEF have estimated that 1.1 billion people worldwide especially in rural areas and low income communities do not have access to safe drinking water (WHO and UNICEF, 2000). Several studies have shown that water is a source of various waterborne infectious diseases. The most common waterborne disease in the developing world is diarrhea (Clasen et al., 2014). This illness is the fourth leading cause of death among children under five years globally (WHO, 2015). 80% of diarrhea cases are attributable to unsafe water supply, inadequate sanitation or insufficient hygiene. These cases result in 1.5 million deaths each year, most of them children (Prüss-Üstün et al., 2008).

In the Caribbean and Latin America region, diarrhea is the second highest cause of death in children under five (OPS, 2011). This is the case in Colombia where this illness is the second most prevalent, particularly in the municipalities with lack of basic needs and unsafe water supply. At the same time the rural areas of the country have the highest risk levels for water supply (INS, 2013).

An option to improve the water quality supply in these regions is the use of Point-of-use (POU) water treatment methods. These methods can be grouped into: i) heat and UV-based systems (boiling, solar radiation, SODIS, UV lamps), ii) chemical treatment (coagulation, flocculation and precipitation, adsorption, ion exchange, chemical disinfection) and, iii) physical removal processes (settling and filtration including membranes; ceramic and fibers filters; granular media filters with sand filters; and aeration) (Peter-Varbanets et al., 2009).

In the last 20 years, POU ceramic water filters have gained

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widespread use around the world as a low cost method to produce safe drinking water (Bielefeldt et al., 2009). Additionally, decentralized membrane systems designed for remote areas of developing countries are now available (Peter-Varbanets et al., 2009).

There is a growing number of literature on household water supply treatment. Various methods such as slow sand filtration (Elliott et al., 2011), candle ceramic filters (Franz, 2005; Sobsey et al., 2008; Mwabi et al., 2011), pot ceramic filters (Lantagne, 2001; Campbell, 2005; Bielefeldt et al., 2009) and membrane filters (Naranjo and Gerba, 2008; Walters, 2008) have been reported. In Colombia there are few reports mainly concentrated in candle ceramic filters (Clasen et al., 2005) and pot filters (Vidal, 2010; Lerman, 2012). The feasibility of these systems for the removal of suspended solids and micro-organisms has been proven. However, most of the evaluations have been carried out in short periods of time (Mwabi et al., 2011).

The aim of this study was to evaluate under laboratory conditions the long term performance of four household filter systems used for the production of water supply. The evaluation was made in terms of turbidity, *Escherichia coli* and TDS removals. Also aspects such as filtration rate, characteristics of the cleaning activities and its relation were taken into account. The evaluated POU systems were: 1 and 2 candles ceramic filters (1CCF, 2CCF); pot ceramic filter (PCF) and membrane filter (MF).

2. Materials and methods

The research was done in the Laboratory of Environmental Studies of the University of Boyaca (Tunja, Colombia). The four systems were evaluated at an average temperature of 13 °C over 14 months with an idle time caused by a failure of the deionized water production equipment between the 269 and 294 days. The characteristics of the POU systems are shown in Table 1.

2.1. Raw water

The prepared daily volume of raw water was 7.5 L of deionized water per filter system. This is the minimum recommended by the World Health Organization for drinking and food preparation per person per day (Howard and Bartram, 2003). The raw water that was spiked with chemicals and bacteria of interest had an average turbidity of 34 ± 5.7 NTU, Total Dissolved Solids (TDS) of 1812 ± 513 mg/L, Conductivity of 2564 ± 222 μS cm^{-1} and *E. coli* of 1×10^5 CFU/100 mL. This procedure was made following the recommendations of the Environmental Protection Agency Protocol (EPA, 1987) and by different authors as described in Table 2. The spiking of the water was made with Kaolin for Turbidity and analytical grade NaCl (Merck) for TDS.

2.2. E. coli preparation

The *E. coli* strain (ATCC 95922) was obtained from the American Type Culture Collection (Rockville, MD.T). The strain was confirmed by cultural tests according to standard methods (SM9225C) using selective media (Chromocult Coliform Agar, Merck, 118441) (APHA et al., 2012). To obtain the initial concentrations that were spiked into the deionized water, one loop of each bacterium was grown in Brain Hearth Infusion (BHI) broth (Oxoid, CM1135) in 50 mL Falcon tubes. The tubes were incubated in a shaking incubator (IKA, Model KS 4000) at 37 ± 1 °C for 12 ± 1 h at 180 ± 10 rpm. To facilitate the spiking of *E. coli* the turbidimetric method (Hogg, 2005) using a spectrophotometer (Genesys TM 10S UV–Vis) was implemented. A calibration graph with the relationship between the absorbance at 500 nm and the CFU/mL was made to determine the required volume and concentration of *E. coli* needed to spike the raw water.

2.3. Spiking of the raw water

Aliquots of 1 mL with a concentration of 6.2×10^9 CFU/100 mL were inoculated daily into 65 L of deionized water. The spiked water samples were mixed vigorously using a Stir-Pak laboratory mixer (Cole-Parmer EW-50007-20) before passing 7.5 L through each filter.

The concentration of *E. coli* before and after filtration was quantified weekly by the membrane filter (MF) technique, using Chromocult Coliform Agar (Merck, 118441) and a filter pore size of 0.45 μm (Millipore, HAWG047S3), as described in the standard methods (APHA et al., 2012).

2.4. Measurement of the performance variables

The performance of the systems was evaluated with variables shown in Table 3. The concentration of TDS as well the levels of Turbidity, Color, pH and Conductivity in the raw and the filtrated water were measured weekly using the standard methods (APHA et al., 2012). Turbidity and Color were measured using a portable meter (HACH 2100N). Temperature and pH were measured with a Schott pH meter (Handylab) and Conductivity with a Metrohm conductivity meter (712 Model).

The maintenance and cleaning activities were as follows.

- **MF**: The maintenance was undertaken daily, washing the prefilter with clean water to remove trapped gross material (>80 μm). Before starting the filtration a purge of 30 s was made by pressing the purge valve three (3) times.
- **1CCF and 2CCF:** During the first 255 days of operation, the filter receptacles of raw and filtrated water were cleaned daily by flushing with tap water. The candles were cleaned manually. Between 165 and 195 days kaolin accumulation in the water receptacle was observed and the turbidity of the filtrated water increased. This impediment was overcome by cleaning the receptacle with tap water, and rubbing the walls with hands. The filtration rate was improved after day 258 by cleaning the candles once a week with a soft bristle brush.
- **PCF**: In the first 255 days the pot was cleaned daily with clean water rubbing the wall with hands. Later, to improve the filtration rate it was done with a soft bristle brush.

The statistical comparison of the performance of the systems was made by using descriptive tests of variance ANOVA and POSTANOVA using the Tukey's Honest Significance Difference method. The statistical analysis was made with the R-Project free software.

3. Results and discussions

3.1. Raw water

Table 4 shows the statistical analysis of the physicochemical and microbiological variables measured in the raw water during the study. The low Variation Coefficient (VC) of turbidity, *E. coli*, pH, Conductivity, TDS and Color is an indication of the low variability of the raw water.

3.2. Performance of the filtration systems

Fig.1 shows the boxplot diagrams for the variation of filtrated water turbidity. The observed removal efficiency for the membrane filter reached is on average 99.3 ± 0.34% (0.22 ± 0.09 NTU). These values were similar to those reported by Iwana Green (2010) and comply with the Colombian regulation (2.0 NTU) and international