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Full Length Research Paper

Implementation of biosand filters in rural area for drinking water production

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A concrete biosand filter (BSF) was designed, and its performance was evaluated on three different water used in the rural communities. The field study was conducted by using tap, well and pump waters, and a questionnaire was administered to apprehend the community's attitudes in the BSF utilisation. BSF performance was characterised by analysing the filtrates concentration in NH_4^+, NO_3^-, NO_2^-, COD, *Escherichia coli*, and *Clostridium perfringens*. The BSF was approved by 94% of the population for water quality, ease of use and quantity of clean water produced. The main results are effective removal of microorganisms (*C. perfringens*, *E. coli*), chemical transformation and removal of NH_4^+, NO_3^- and COD at concentrations below WHO drinking water standards. BSF technology could be a solution in the provision of portable water to rural areas and might represent an alternative for the use of expensive bottled water.

Key words: Biosand filter, drinking water, rural communities, tap water, well, pump.

INTRODUCTION

In developing countries, rural communities water infrastructures are either poorly developed or non-existent (Hoque et al., 2006; Varbanets et al., 2009). As a consequence, girls and women are forced to collect their water from river, groundwater, or ponds on long distance (Arnal et al., 2010). These water resources are often faecally, microbiologically or chemically (nutriments, pesticides, heavy metals etc.) contaminated and not treated before utilisation (Meng et al., 2001). This can cause diarrhoeal disease for example. In 2004, World Health Organisation (WHO) estimated that throughout the developing world, an overall of 1.1 billion people lack access to improved water supplies, causing each year the death of 3.4 million people, most of them children because of water-related disease.

On the other hand, point of use (POU) drinking water treatment has been identified as one of the most promising and accessible technology for treating water at the household level (Sobsey, 2007) in developing countries because of their low price, simple, efficiency, easy to use and to maintain (Elliott et al., 2006). The biosand filter (BSF) is a modification of the traditional slow sand filter that can be built on a smaller scale. The BSF has been developed and tested by various government, research and health institutions, as well as by non-governmental agencies (Elliott et al., 2008; Mangoua et al., 2009). This technology might be a solution in the provision of portable water to rural areas (Cidu et al., 2011) but few studies have shown that NH_4^+, chemical oxygen demand (COD) and microorganism's presence may constitute problems in BSF in productive agricultural area and tropical area, and also the acceptance of population. The main objectives of this study were; (i) to record the user's perceptions on the performance of BSF and (ii) to evaluate the BSF efficiency as removing bacteria (*Clostridium perfringens* and *Escherichia coli*) and pollutants (NH_4^+, NO_3^-, NO_2^- and COD) of tap, well and pump waters in rural communities.

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Abbreviation: BSF, Biosand filter.

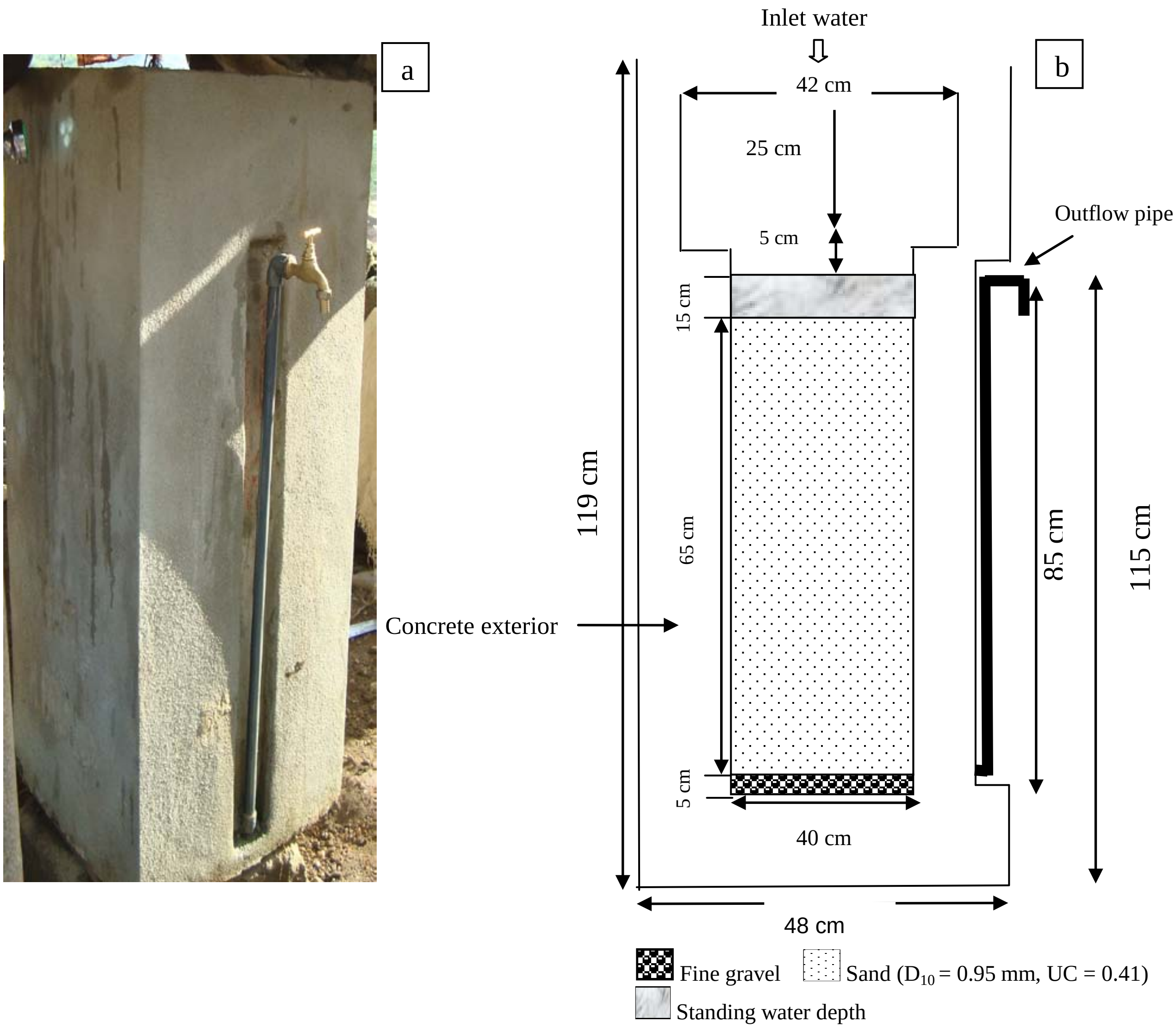

Figure 1. Photography (a) and dimensions (b) of the concrete BSF.

MATERIALS AND METHODS

Filter design

A concrete biosand filter was built (Figure 1) using cement, sand and polyvinyl chloride (PVC) pipe. The exterior and interior dimensions of the concrete BSF are indicated in the figure. The interior of the BSF was filled with 5 cm of granitic gravel (20 × 15) and 65 cm of coarse uniform sand constituting the filter media. This media had an effective diameter size (D_{10}) of 0.95 mm with a uniformity coefficient (UC) of 0.41. The outlet pipe was designed in such a manner that a water depth of 15 cm was maintained above the filter media.

Field site description

The study was conducted in three villages near Abidjan (Côte d'Ivoire): Thomasset, Kougloboye and Blondey. They are located at a distance more or less 40 km from Abidjan, north of this district. The distributions of BSF in these villages are as follows: four at Thomasset and at Blondey and five at Kougloboye.

Water sources

The water sources used by the population in the villages are: at Thomasset, a well equipped with a foot pump, an open well at Kougloboye and a tap water at Blondey.

Community perceptions and water sampling and analysis

The population perceptions were apprehended after the administration of questionnaire on the BSF design, water quality produced and filters management. An interview and focus group discussion was organised. The BSF performance was characterised by analysing the influent and effluent concentrations in *E. coli*, *C. perfringens*, ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-) and chemical oxygen demand (COD). In addition, the pH of

Table 1. Mean average and standard deviations of physico-chemical and bacteriological parameters of raw waters used.

Parameter	N	Raw water used		
		Well	Pump	Tap
pH	12	4.6±0.12	6.8±0.37	6.9±0.17
NH_4^+ (µg L^{-1})	12	448±139	497±158	48±21
NO_2^- (µg L^{-1})	12	32±12.7	9.36±41	9.34±4.7
NO_3^- (mg L^{-1})	12	3.4±1.4	3.9±1.3	0.94±0.6
COD (mg L^{-1})	12	34.5±3.7	67.3±12.5	68.3±17.1
Escherichia coli (CFU/100 mL)	8	0.625±0.91	0.5±1.06	0.5±1.06
Clostridium perfringens (CFU/100 mL)	8	0	0.375±0.74	0.125±0.35

N, Sample number.

the water and the BSF clogging were studied. The water quality obtained was compared with the drinking water according to WHO (2008). Water samples were taken in the raw water applied and in the filtrates, once a week on one BSF per village and conserved at 0°C until analysis. The pH was measured using a multi parameter (Model C830 consort). The concentrations of NH_4^+, NO_2^-, NO_3^- and COD of the samples were analysed following the analytical standard methods (AFNOR) specific for each parameter. Two microbial tests were used to determine the concentration of water in *E. coli* and *C. perfringens*. The Rapid' *E. coli* 2 method was used to analyze *E. coli* and the trypticase-sulfite-neomycine (TSN) was used for *C. perfringens* concentration determination.

RESULTS AND DISCUSSION

Community perceptions

One way to improve acceptance of a technology by a community is to associate human to its development. In this context, the BSF have been exposed in three rural villages to apprehend the community's attitude in their utilization. The statistics reveal good satisfactory (94%) of the population regarding the design of the BSF. They also appreciated the facility of using and maintaining the BSF. Concerning the quantity of the water treated (20 L/h), this volume gives satisfaction to the communities because it covers a lot. This level of population opinion about the BSF was higher than that obtained in Nepal (89%) by Paynter (2001), but slightly lower than that obtained in Haïti (99%) (Duke et al., 2006) and in Nicaragua (100%) (Vanderzwaag, 2008). Concerning the utilization of the water produced by the BSF, communities used them for drinking, bathing, cooking and housework. These utilizations are similar to those found by different authors (Donison, 2004). All of the population investigated noted a good clearness of the BSF filtrates and revealed that these filtrates smelled better than the source water. They did not make any observation on the change of taste. All BSF users suggest that the PVC outlet pipe may be fixed on the filter body to avoid its destruction.

Raw water composition

The mean values of the physico-chemical and bacteriological parameters of the raw waters used are consigned in Table 1. One could observe that the different water sources (well, pump and tap water) displayed acidic pH values. The raw water pH values varied between 4.6 and 6.9. The sequence of mean values was: well water (4.6) < pump water (6.8) < tap water (6.9). The raw waters used almost did not contain pathogenic germs (less than 1 colony). Concerning the other parameters, they significantly varied from one water source to another. Except for COD, the low mean concentrations of NH_4^+, NO_2^- and NO_3^- were recorded in the tap water.

Biosand filter performance

pH

Figure 2 shows the pH variations of the different raw and treated waters following time. One could observe that the pH of the different effluents was higher than that of the raw waters. For example, the pH mean values of the tap water (6.8) and the pump water (6.7) were less acidic in comparison to that of the well water (4.6). After the treatment, these pH values became near neutral to slightly basic [tap water (7.4), pump water (7.1), and well water (8.3)]. This pH increase could be explained by the dissolution of carbonate materials hosted in the sand and the concrete (Elliott et al., 2006). Indeed, the lagoon sand used within this study contained shells which could constitute natural sources of carbonate. The dissolution of their shells could enhance pH in the filtrates. All of the pH of these effluents respect the WHO drinking water guide (6.5 < pH < 8.5) (WHO, 2008).

Ammonium and its derivatives (NO_2^-, NO_3^-)

The influent and effluent NH_4^+ concentrations are presented in Figure 3. One could observe that NH_4^+ removal rate for open well and pump water (89%) was highest compared to tap water (64.8%). $NH4^+$ concentration decreasing in the effluents could be caused by its absorption on BSF materials (Metcalf and Eddy, 2003) or oxidation by nitrifying microorganisms (Ward,

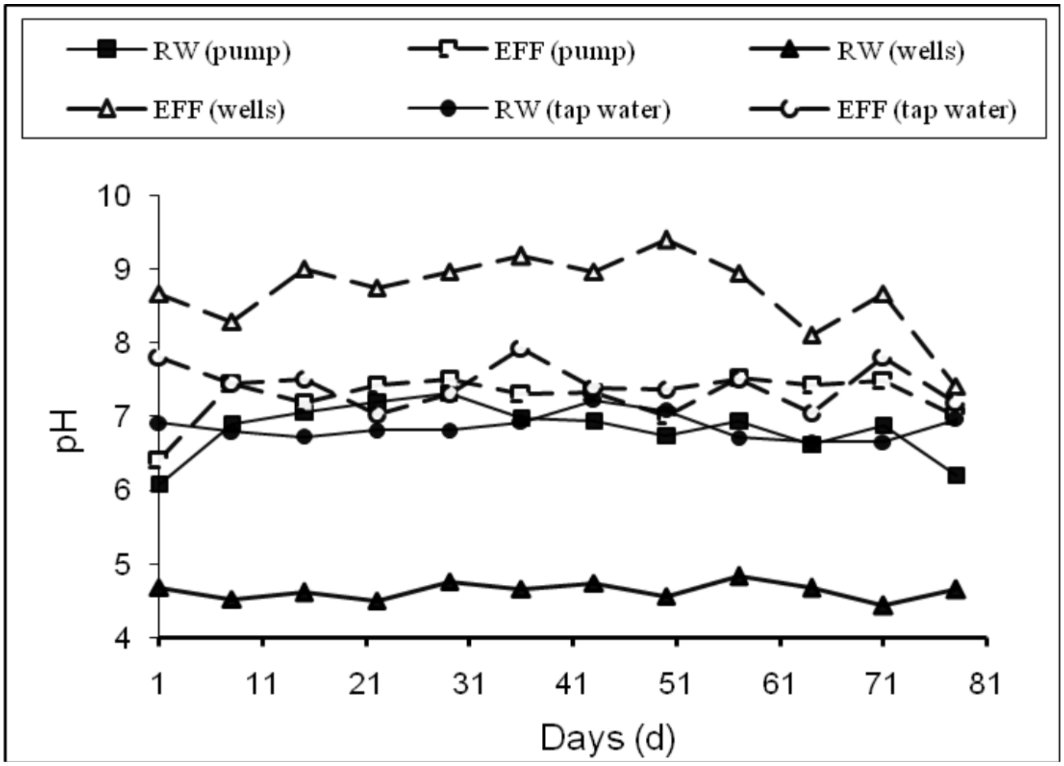

Figure 2. pH profiles of the raw and treated waters during 81 days; RW (pump), raw pump water; EFF (pump), pump effluent; RW (well), raw well water; EFF (well), well effluent; RW (tap water), raw tap water; EFF (tap water), tap water effluent.

2008; De Vet et al., 2009). The rate of NH_4^+ removed was similar to previous values in the literature (60 to 99%) (Rodgers et al., 2004). Concerning NO_2^- profiles in both raw and treated effluents, they are presented by Figure 4. One could observe an increase of NO_2^- concentrations in the filtrates (tap water = 31 μg L^{-1}, pump = 586 μg L^{-1}, and well = 599 μg L^{-1}) than in raw waters (tap and pump = 9.3 μg L^{-1}, well = 32 μg L^{-1}). Similar results have been reported about sand filters activities (Stauber, 2010). This accumulation of nitrites could be explained by a high activity of nitritation and a limited activity of nitratation because of low carbon source and hydraulic retention time (HRT). The profiles of NO_3^- in the filtrates and the raw waters are shown in Figure 5. NO_3^- concentration decreased in the effluents than in the influents (raw waters). This decrease of NO_3^- concentration could be a consequence of denitrification. According to Al-Yousef (1990), during the filtration, nitrification is taking place in the upper aerobic layers of the BSF; it follows a denitrification which could reduce NO_3^- concentration in the filtrates, comparatively to the raw waters. The removal of NO_3^- was variable with the raw water source: 64 ± 12.8% for tap water, 73 ± 21% for well and 81 ± 25.7% for pump. These results were much higher than those obtained in Ethiopia (20%). The variation of the results between these two works could be explained by the raw water quality and the manner that experiments have been conducted by the authors. Furthermore, the treatment efficiency achieved in this work with the BSF is within the same order of results in literature (50 to 90%) (Vanderzwaag, 2008). Comparing the NH_4^+, NO_2^- and NO_3^- concentrations of the BSF effluents, one could find that they are lower than WHO drinking water standards (WHO, 2008).

Chemical oxygen demand (COD)

Figure 6 shows COD concentrations variations within raw waters and BSF effluents. The COD concentrations were lower in the effluents than in the raw waters. Comparing the mean values of raw waters COD, the following sequence appeared: open well (11.93 mg L^{-1}) > tap water (9.04 mg L^{-1}) > pump water (6.57 mg L^{-}1). This sequence could be explained by litter introduction (dusts, solid matters etc.) in the first two water sources by infiltration or wind actions. The low concentration of COD in the latest water source is due to its protection against wind action because of the site management. COD removal was higher in the pump water (90.3%) and the tap water (86.2%) than in the well (66%). The COD reduction in the effluents after filtration may be due to organic particular matters retention within the BSF or their biological oxidation (Pasztor et al., 2009). The easy assimilative

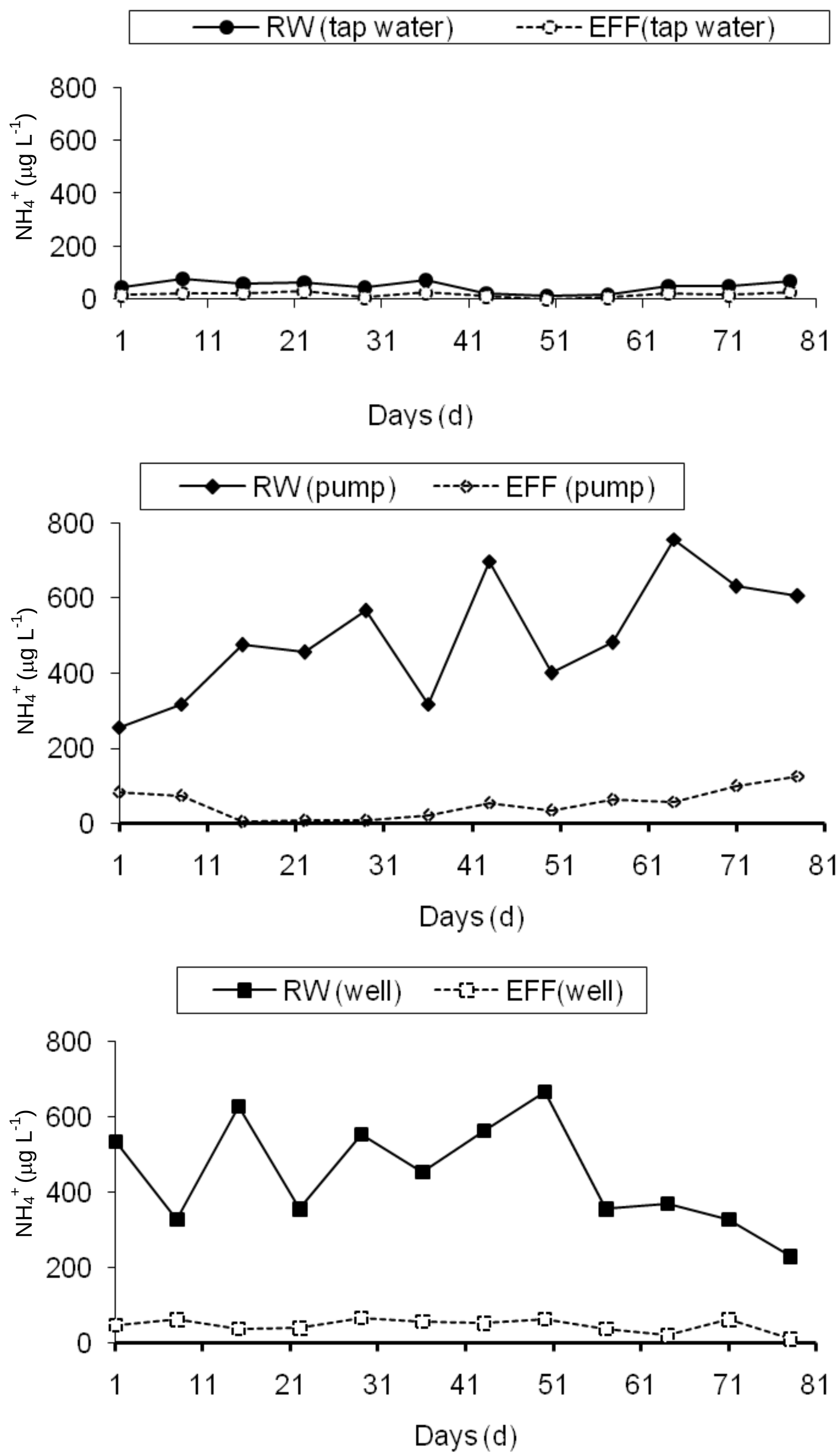

Figure 3. Ammonium (NH_4^+) profiles of the raw and treated waters during 81 days; RW (pump), raw pump water; EFF (pump), pump effluent; RW (well), raw well water; EFF (well), well effluent; RW (tap water), raw tap water; EFF (tap water), tap water effluent.

carbon source has certainly been used for denitrification microorganism's carbon generation or maintenance. Indeed, these microorganisms would need carbon source to elaborate their energy.

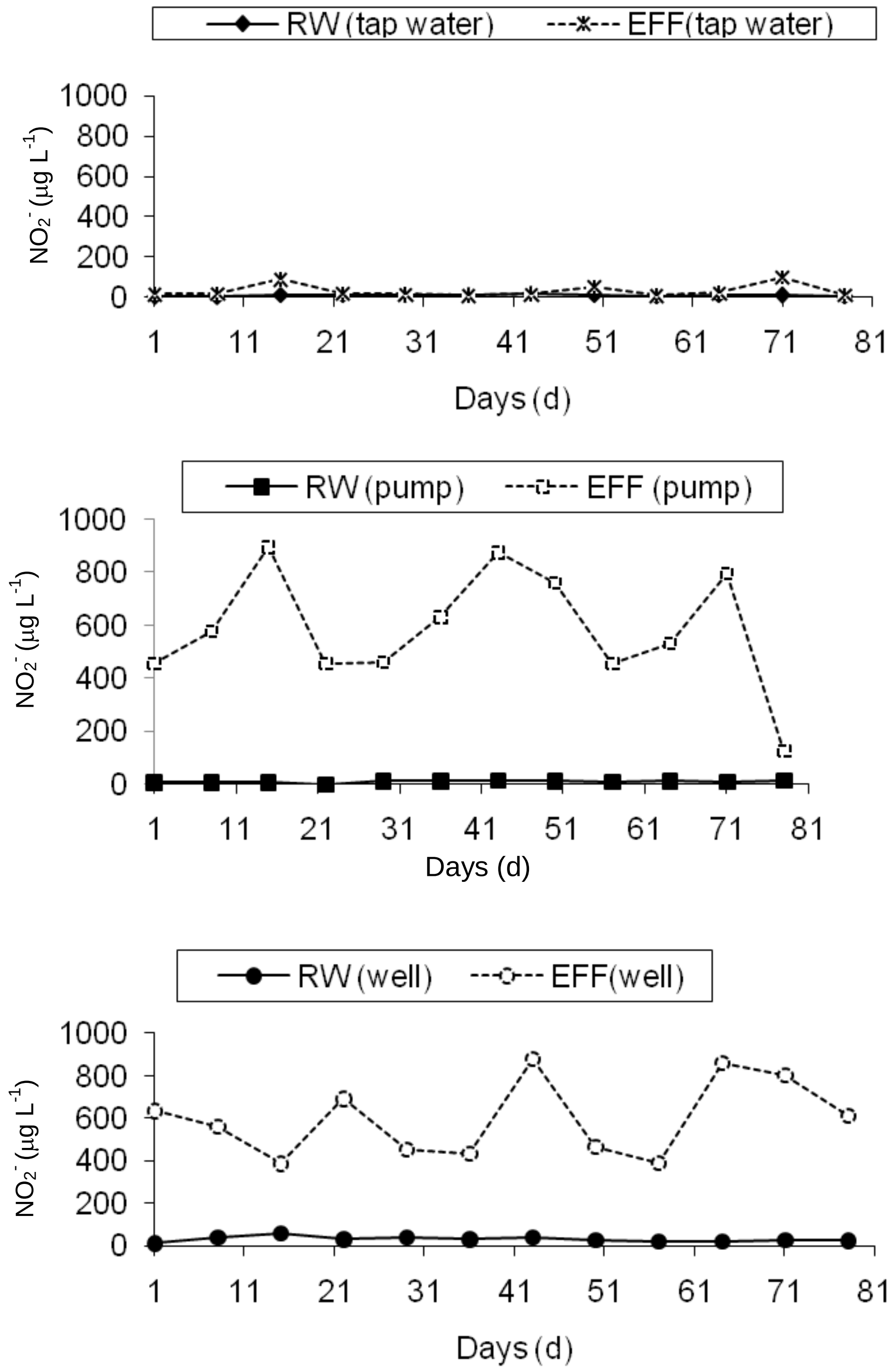

Figure 4. Nitrite (NO_2^-) profiles of the raw and treated waters during 81 days; RW (pump), raw pump water; EFF (pump), pump effluent; RW (well), raw well water; EFF (well), well effluent; RW (tap water), raw tap water; EFF (tap water), tap water effluent.

C. perfringens and E. coli

Tables 2 and 3 present *C. perfringens* and *E. coli* concentrations in both raw waters and effluents. The concentrations of these pathogens in the raw waters were in the range of 0 to 3 CFU/100 mL. After their filtration on the BSF, the entire microorganism colonies were removed (100%). The mechanisms implicated in bacteria removal by the BSF could be: adsorption, physical straining and natural die-off of the microbial because of lack of carbon source (Elliott et al., 2006). The results obtained in this research are in the same order (74 to 99.9%) of different BSF experimented worldwide (Baker and Duke, 2006; Baumgartner et al.,

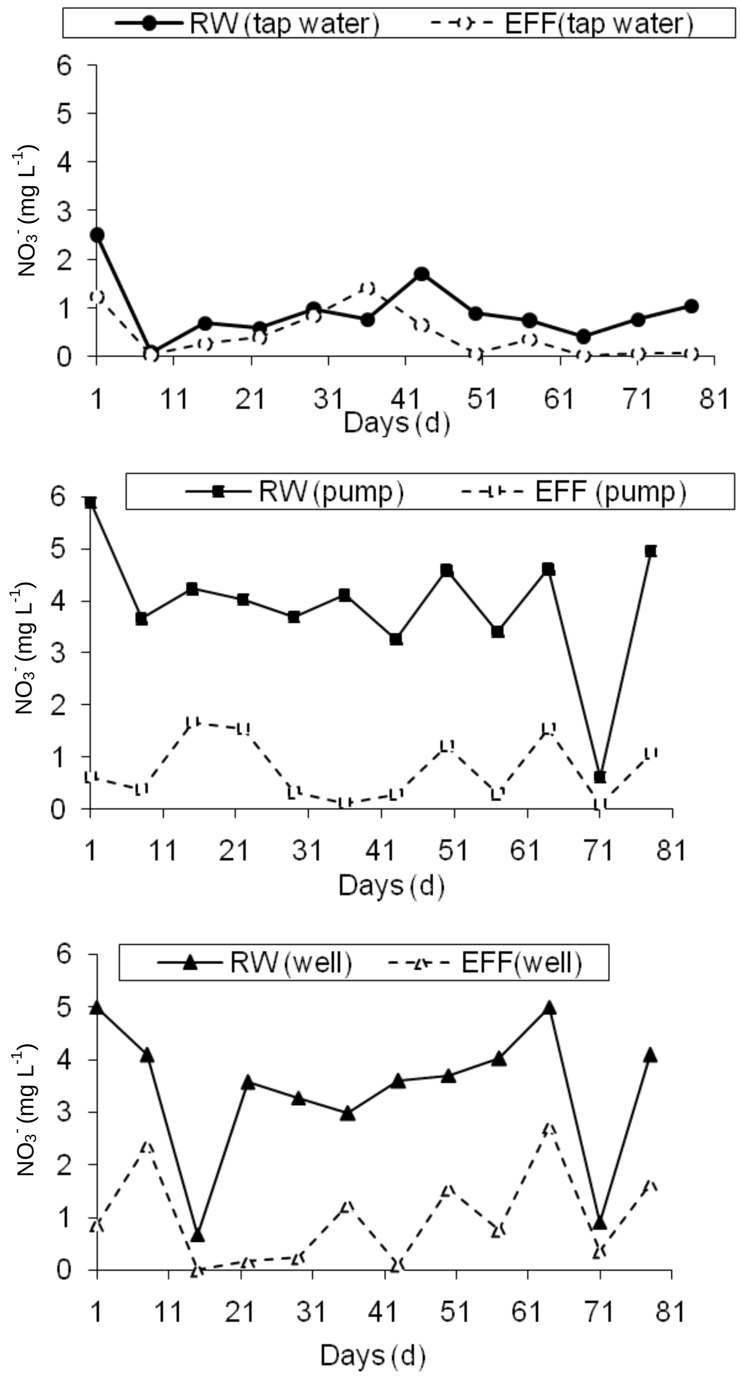

Figure 5. Nitrate (NO_3^-) profiles of the raw and treated waters during 81 days; RW (pump), raw pump water; EFF (pump),pump effluent; RW (well), raw well water; EFF (well), well effluent; RW (tap water), raw tap water; EFF (tap water), tap water effluent.

2007; Vanderzwaag, 2008; Fiore et al., 2010).

Conclusion

The BSF exposed in the rural area have been adopted by this community and they have contributed to improve the outlet PVC pipe construction. The BSF users were satisfied with the filters they have received because of their contribution to water potabilisation. About the water quality, the BSF accomplished significant pollutants removal and transformation under WHO drinking water

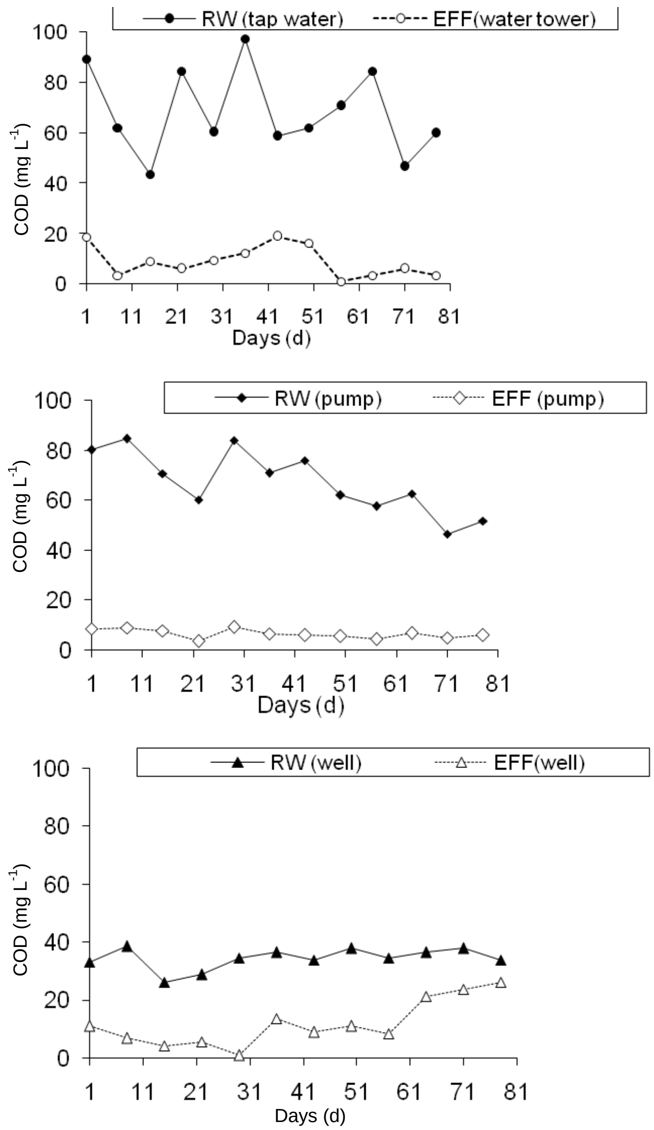

Figure 6. COD profiles of the raw and treated waters during 81 days; RW (pump), raw pump water; EFF (pump), pump effluent; RW (well), raw well water; EFF (well), well effluent; RW (tap water), raw tap water; EFF (tap water), tap water effluent.

Table 2. *C. perfringens* concentration in the raw and treated waters.

Day (d)	Tap water			Well water			Pump water		
	UFC/100 mL		(%)	UFC/100 mL		(%)	UFC/100 mL		(%)
	RW	EFF	R	RW	EFF	R	RW	EFF	R
7	1	0	100	0	0	-	0	0	-
14	0	0	-	0	0	-	0	0	-
21	0	0	-	0	0	-	0	0	-
28	0	0	-	0	0	-	0	0	-
35	0	0	-	0	0	-	0	0	-
42	0	0	-	0	0	-	2	0	100
49	0	0	-	0	0	-	1	0	100
56	0	0	-	0	0	-	0	0	-

RW, Raw water; EFF, effluent; R, percentage removal.

Table 3. *E. coli* concentration in the raw and treated waters.

Day (d)	Tap water			Well water			Pump water		
	UFC/100 mL		(%)	UFC/100 mL		(%)	UFC/100 mL		(%)
	RW	EFF	R	RW	EFF	R	RW	EFF	R
7	0	0	-	2	0	100	0	0	-
14	0	0	-	0	0	-	0	0	-
21	1	0	100	0	0	-	1	0	100
28	0	0	-	0	0	-	0	0	-
35	0	0	-	1	0	100	0	0	-
42	3	0	100	2	0	100	0	0	-
49	0	0	-	0	0	-	0	0	-
56	0	0	-	0	0	-	3	0	100

RW, Raw water; EFF, effluent; R, percentage removal.

standards concerning *C. perfringens*, *E. coli*, NH_4^+, NO_3^- and COD. This innovative decentralized treatment technology could be a solution in the provision of portable water to rural areas because of it is easy to construct, operate and maintain. Also, it might represent an alternative of using expensive bottled water.

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