

# Household Drinking Water Treatment Methods: Assessment of Current Practices and Experimentation with Unadopted Solutions

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## Abstract

One of the key strategies for preventing waterborne diseases, as recommended by the World Health Organization (WHO), is household water treatment. This study aims, on the one hand, to assess the effectiveness of the water treatment methods used by households (Javel water, boiling, and Aquatab), and on the other hand, to enhance household knowledge of alternative treatment options such as continuous chlorination and ceramic filtration. To achieve this, twenty-six wells were selected: sixteen were monitored throughout their water treatment stages, while ten served as test samples for two treatment methods not commonly applied by households (continuous chlorination and ceramic filtration). Six microbiological parameters (presumed coliforms, thermotolerant coliforms, *Escherichia coli*, fecal streptococci, sulfite-reducing bacteria, and fecal enterococci) were analyzed in the water samples before and after treatment during the dry season (February and October) and the rainy season (August). The collected data were processed using XLSTAT and ArcGIS software, and the HACCP model was applied for data interpretation. Boiling achieved 100% elimination of most microorganisms, except for fecal enterococci, which were detected in 40% of the treated samples, with mean concentrations of 2.67 CFU and 1.92 CFU for the two monitoring periods, respectively. In all water samples treated with Aquatab, although sulfite-reducing bacteria were completely eliminated, other microorganisms (presumed coliforms, thermotolerant coliforms, *Escherichia coli*, fecal streptococci and fecal enterococci) were still detected. The efficiency rates ranged from 94.69% to

100%, with log removal values (LRV) between 1.27 and 3.87  $\log_{10}$ . Furthermore, in all wells treated with 1.5 liters of Javel water, none exhibited adequate residual chlorine levels (0.3 mg/L) 48 hours after treatment. The measured residual chlorine values ranged between 0 and 0.02 mg/L. Regarding the experimental methods, continuous chlorination achieved up to 80% microbial elimination, with residual chlorine maintained in the water up to the 21st day after treatment. Efficiency rates varied from 98.04% to 100%, and LRVs from 1.64 to 4.07  $\log_{10}$ . The use of ceramic filters demonstrated treatment efficiencies ranging from 98.77% to 100% and LRVs between 1.83 and 5.28  $\log_{10}$ . However, two out of five filters showed design flaws, which may have affected their performance. The findings could help to sustain water quality improvement for the local communities in the developing countries.

### Keywords

Kandi City, Drinking Water, Bacteriological Analysis, Treatment Method, Effectiveness

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## 1. Introduction

Water treatment is the set of processes aimed at eliminating unwanted particles, pollutants, and microorganisms to make water suitable for a specific use [1]. Its aim is to eliminate impurities, and the treatment processes are adapted according to the needs. The different water treatment techniques are physical or natural processes (use of filtering devices, heating or plants), chemical treatments (use of chemicals), and mixed treatments (combined use of filtration and chemicals) [2].

The safety of drinking water remains one of the major challenges to be addressed. In humans, the ingestion of water contaminated by human or animal feces [3] leads to significant microbial risks. Thus, the use of untreated drinking water associated with insufficient sanitation and poor domestic hygiene are factors that contribute significantly to deaths caused by diarrheal diseases, particularly in children under 5 years of age. In this age group, nearly 7,600,000 cases of annual death are linked to diarrheal diseases in developing countries [4]. Indeed, each episode of diarrhea reduces caloric and nutrient intake and contributes to delayed growth and development of children [5]. In 145 developing countries, factors of degradation of water quality have been identified along the supply chain [6]-[12]. These include, among others, the unclean environment around water points and the poor management of water collection methods, which promote the transfer of bacteria from surfaces to water points [13] [14]. Insufficient cleaning of water containers and a lack of hygiene during water point maintenance are also contributing factors. All these aspects contribute to the deterioration of the bacteriological quality of water. Thus, to eliminate pathogenic germs in the water of these poorly maintained water points and avoid waterborne diseases, water treatment methods, such as the use of Aquatab tablets, the use of ceramic filters, SO-

DIS, boiling, and continuous chlorination of water are used by households around the world and documented by WHO. Also, several authors [15]-[22] have tested, with satisfactory results, these methods of domestic water treatment in the world, in Africa, and in Benin. However, the main challenge lies in achieving the sustainable and widespread adoption of these techniques.

On the city of Kandi in Benin, 73% of households using water from unconventional sources apply six different water treatment techniques to make water potable [23]. Waterborne diseases persist despite the precautions taken to treat water. However, households believe that certain conditions, including abdominal pain, diarrhea, typhoid fever and skin diseases, are linked to the quality of drinking water [24]. Health risks linked to the use of contaminated water expose households to diseases from a number of outbreaks, proven by [25]-[29]. Since the use of these methods is supposed to improve access to drinking water, ensuring their control is crucial to eliminate pathogens and avoid new risks of contamination. Thus, to help achieve behavioral changes in the application of these drinking water purification techniques, it is essential to find solutions commonly adapted to the households. Therefore, monitoring the water treatment route using single chlorination methods such as sodium hypochlorite, Aquatab tablets, and boiling would allow the identification of critical points of recontamination or incomplete elimination of pathogenic germs contained in the treated water.

This study aims to evaluate the effectiveness of the treatment methods implemented by households (Javel water, boiling, and Aquatab). So it will contribute to the knowledge of households of other methods in particular: continuous chlorination and the use of ceramic filters.

## 2. Materials and Methods

### 2.1. Study area

The study area is the city of Kandi (2° 54'38" - 2° 58'00"E and 11° 6'18" - 11° 9'30"N), one of the municipalities of the Alibori Department in northeastern Benin. It covers approximately 1437 km<sup>2</sup> (Figure 1). The city experiences a Sudanian climate with a unimodal rainfall pattern, characterized by a rainy season extending from May to September and a single dry season from October to April. The highest rainfall occurs in July, August, and September, with respective averages of 226.01 mm, 246.11 mm, and 169.37 mm recorded over the period from 1992 to 2022. These months promote increased water availability in most water points, with static water levels rising closer to the ground surface. However, rainfall and surface runoff facilitate the infiltration of contaminants from household waste (leachate) and wastewater basin into water sources, thereby exacerbating microbial pollution. As a result of such infiltration, many wells host insect larvae in the water, which prompts households to treat their well water using various water purification techniques. Maximum temperatures are recorded in February (37.48°C), March (37.56°C), and April (35.57°C). These high temperatures lead to intense evaporation, which further reduces water availability and increases the demand

among the population. During this period, households face significant challenges in accessing water, with many wells drying up, resulting in increased exposure to water scarcity and waterborne diseases. Otherwise, the city of Kandi is characterized by the presence of fine to medium ancient sandstones, breccia, silt, clay, and coarse deposits distributed along the Kandi fault. Conglomerates are also found in the area, which, although sometimes less productive than sandstones, are suitable for drilling at depths greater than 80 meters. Shallow groundwater is typically located at depths between 5 and 15 meters, with flow rates ranging from 1 to 20 m<sup>3</sup>/h and a drilling success rate exceeding 80% [30]. The Kandi basin contains two main aquifers [31]: the Cambro-Ordovician aquifer, known as the Wèrè Formation, and the terminal Ordovician-Silurian aquifer, known as the Kandi formation.

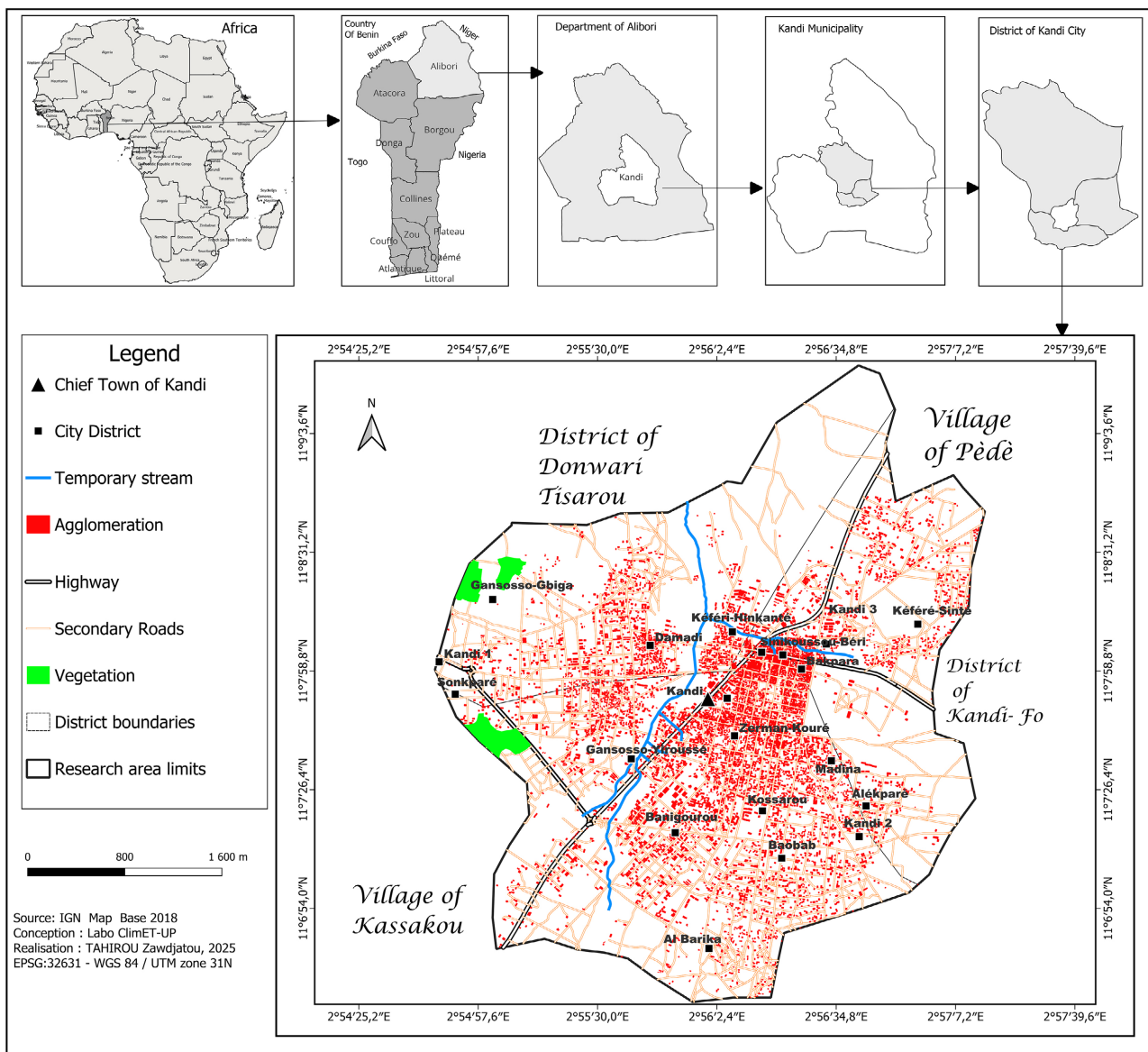


Figure 1. Map showing the geographical location of the city of Kandi in Benin.



3) using the Active Participatory Research Method (MARP) of [33]. On the other hand, 26 wells distributed in different parts of the city (**Figure 2**) were selected for the water sampling.

Selection criteria comprised one household per dwelling with a well and households without wells that use well water; key informants possessing local knowledge on water treatment were also included.

### **2.3. Assessment of the Well Water Treatment Practices on the Households**

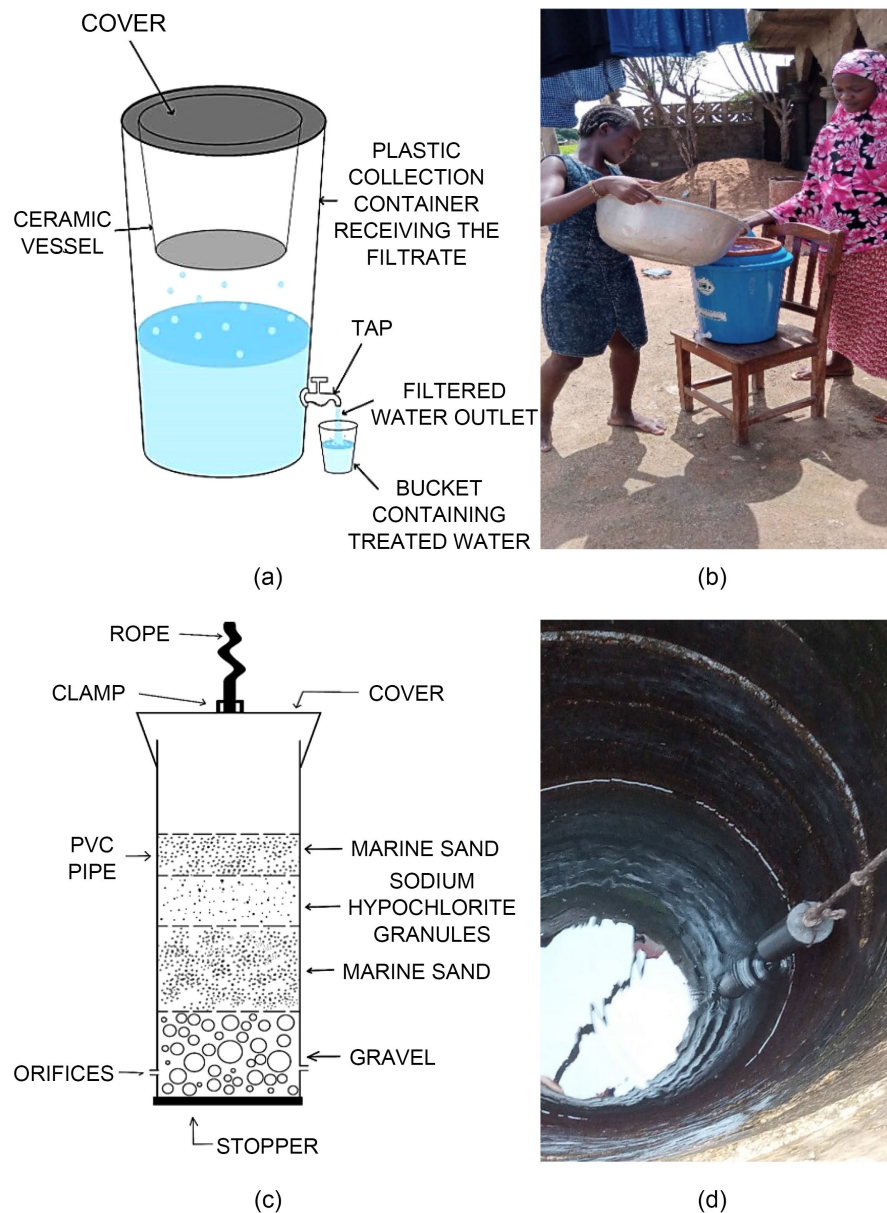
To assess the well water treatment technique, we take into account the number of households that apply the investigated techniques and that use the treated water for drinking. Thus, on this basis, the use of Aquatabs tablets, Javel water, and boiling are the most concerned techniques. This allowed the monitoring of the water treatment stages in households over a period of seven days. In total, sixteen wells were monitored in households of different neighborhoods and divided into groups of five for boiling and aquatabs techniques, and six for wells treated with Javel water. The elimination of previously sought germs (presumed coliforms, thermotolerant coliforms, *Escherichia coli*, fecal streptococci, sulfite-reducing and fecal enterococci) after application of these treatment techniques, was verified through water analyses in the laboratory before and after the treatment process for the practice of boiling and aquatab. Furthermore, the water from the Javel water-treated wells was monitored through the control of residual chlorine using a chlorine comparator per time interval, until total disappearance of chlorine.

### **2.4. Choice and Presentation of Experimental Methods**

Two water treatment techniques not commonly used in households are considered as experimental practices. The first is a water filtration by the ceramic filters (physical treatment). This technique was chosen because households often use fabrics for water filtration, and it is easy to implement. The second technique is the continuous chlorination using chlorine diffuser pots (chemical treatment), which relates to the use of chlorine in other forms (such as aquatabs and Javel water) by households. Additionally, the ceramic filters being used are manufactured by the Songhai center in Porto Novo, Benin. These filters consist of plastic devices with a tap and a clay pot impregnated with colloidal silver, which has antibacterial properties. The pot is made from a mixture of clay and organic matter (like sawdust) [34]-[38] that is dried and then baked in an oven at 900°C for 8 hours. The filtration procedure involves cleaning the filter and introducing water into the ceramic pot.

As for the model of chlorinate diffuser pot designed and used in wells, they are models already tested by [39] [40]. It is made using a PVC pipe with a diameter of 100 cm and a length of 50 cm. The pipe is capped at both ends and is equipped with two holes 3 cm from its lower base, through which the chlorine diffuses upon contact with the water on the well. From bottom to top, the pot contains layers of

gravel, fine sand, hypochlorite granules and a final layer of fine sand as lid. The installation of the device is done before a preliminary cleaning of the wells to extract suspended matter (dead leaves, sachets, wood and mud). It is suspended using a rope attached to the internal walls of the wells, at a required immersion depth of approximately 10 cm in the water (**Plate 1(d)**). The pot is adjusted to keep it in the water. The wells selected are those with nozzles and a rim. Other factors, such as the low turbidity of the well water, pH, temperature, and the agreement of the owner (private wells) or the neighborhood representative (community wells) were also taken into account. The characteristics of these wells are presented in **Table 1**.



**Plate 1.** (a) Schematic section of the filtration device with ceramic pot; (b) procedure for filtering water with a ceramic filter; (c) diagram of the type of chlorine diffuser pot used, (d) chlorine diffuser pot designed in the well at Hamalaya in Kandi.

**Table 1.** Characteristics of wells sampled for continuous chlorination.

Code	Shape	Well characteristics					Static water level (m)	
		Well	Protection	Diameter (m)	Total depth (m)	Distance (m) wells/latrines	Rainy season	Dry season
P1	Circular	waterproof	Open	1.2	15	11	4	9
P13	Circular	waterproof	Covered	1.4	14	13	5.4	10
P14	Circular	waterproof	Open	1.7	12	10	4.5	8.9
P17	Circular	waterproof	Covered	1.2	10	17	2.3	6.1
P19	Circular	waterproof	Open	1.2	16	13	6	13

## 2.5. Collection and Analysis of Samples of Raw Water and Treated Water

Two sampling and water measurement campaigns were conducted during the dry season (February and October) and the rainy season (August), in 2022 and 2023, respectively. Raw water and treated water samples were collected in 250 mL glass bottles that had been previously washed and sterilized. The bottles were filled directly at the sampling sites, hermetically sealed, and wrapped in aluminum foil to prevent light contamination. Microbiological analyses were performed at the Laboratory of the National Company of Water in Bénin (SONEB) and focused on the detection of presumptive coliforms, thermotolerant coliforms, *Escherichia coli*, fecal streptococci, sulfite-reducing bacteria, and fecal enterococci (Table 2). The results obtained from the various measurements and analyses were subsequently compared with the World Health Organization (WHO) guideline values [3].

**Table 2.** Methods of research and identification of bacteriological germs.

Germs wanted	Culture methods/media	Incubation temperature	Standards/reference
Presumed coliforms	Crystal violet agar with neutral red bile and lactose	30°C in 24 hours	ISO 9308-1:2000
<i>Escherichia coli</i>	Crystal violet agar with neutral red bile and lactose	37°C in 24 hours	ISO 9308-1:2000
Thermotolerant coliforms	Crystal violet agar with neutral red bile and lactose	44°C in 48 hours	ISO 9308-1:2000
Streptococci fecal	Slanetz and Bartley Agar LF 163 462	37°C in 48 hours	ISO 7899-2
Sulfite-reducers	TSN 356 4724 Agar	37°C in 24 hours	-
Fecal enterococci	Slanetz and Bartley BK BM 14608	37°C in 48 hours	NF T 90-421

## 2.6. Data Analysis

### 2.6.1. Calcium Hypochlorite Dosage

The method used to determine the appropriate dosage of calcium hypochlorite granules follows the approach described in [41] [42]. A standardized chlorine dose

of 400 g was applied to all sampled wells. pH and free residual chlorine (FRC) levels were measured using a field test kit (see **Plate 2**). The data collected were then compared to WHO (2017) guidelines for assessing health risks in drinking water.

Analysis was conducted using the HACCP (Hazard Analysis and Critical Control Point) method a systematic approach designed to identify and manage potential risks that could affect water quality and safety [21] [43]. In this study, the HACCP model was applied to the water treatment processes both at the source and at the point of use. The goal is to ensure effective monitoring by identifying critical stages where significant risks may arise.



**Plate 2.** Chlorine dosing kit. **Photography:** R.B Djibril, August 2023.

For the ceramic filters, their flow rate ( $D$ ) was measured to determine the time taken to filter the water using the following formula:

$$D = Vd/t$$

$D$  is the discharge or flow rate ( $m^3/s$ );

$Vd$  is the discharged water volume ( $m^3$ );

$T$  is the flow time or duration (s).

This formula has already been applied by [16] to determine the flow rate of ceramic filters in Burkina Faso.

### 2.6.2. Determination of the Effectiveness of the Water Treatment Techniques

To assess the effectiveness of each method, the results of microbiological analyses of water obtained before treatment were compared with those obtained after treatment and with the WHO guideline values. The effectiveness rate of the applied methods was calculated using the formula [16] [44].

$$E = (C_i - C_f) / C_i \times 100$$

$E$  is the percentage efficiency.

$C_i$  is the concentration of germs present in the water sample before treatment.

$C_f$  is the concentration of the number of germs after treatment.

The reduction of bacteriological germs was also indicated in Log Reduction Value (LRV) which values were obtained from the formula:

$$LRV = (\log_{10} A/B) \text{ ou } LRV = \log_{10}(A) - \log_{10}(B)$$

$A$  is the number of germs present in the water sample before treatment;

$B$  is the number of germs after treatment.

### 3. Results and Discussions

#### 3.1. Monitoring of Water Treatment Practices in Households

##### 3.1.1. Treatment of Well Water with Aquatab Tablets

Microbiological germs variation in the raw well water and treated by aquatabs tablets is presented in **Table 3**.

**Table 3.** Variations in microbiological parameters on the well water treated by Aquatab.

Settings	Raw water				Treated well water by Aquatab				Reduction		
	Average	min	max	Standard deviation	Average	Min	Max	Standard deviation	Efficiency	LRV	
Presumed coliforms Rs	169,628	15,800	393,000	129097.6	34	18	80	18.4	99.97	-	3.69
Presumed coliforms Ds	158915.4	9033	394,000	118067.68	21.2	10	48	10.72	99.98	-	3.87
Thermo-tolerant Coliform Rs	83019.4	7204	221,378	64406.48	11.2	0	20	6.96	99.98	-	3.86
Thermo-tolerant coliform Ds	139384.6	9640	341,500	122333.92	24.8	0	85	24.08	99.98	-	3.74
<i>E. coli</i> Rs	5152.8	1015	8911	2309.04	2	0	5	1.6	99.96	-	3.41
<i>E. coli</i> Ds	3413.6	1004	6912	2165.52	4.2	0	10	3.84	99.87	-	2.90
Fecal streptococci Rs	2845	652	6206	1611.6	8	0	21	9.6	99.71	-	2.55
Fecal streptococci Ds	2518	744	6078	1617.6	8.8	0	19	7.04	99.65	-	2.45
Sulfite Reducers Rs	15.6	9	19	2.64	0	0	0	0	100	0.2	1.89
Sulfite Reducers Ds	4.4	0	9	3.52	0	0	0	0	100	0.2	1.34
Fecal Enterococci Rs	398	80	844	281.2	0	0	11	3.75	100	0.2	3.29
Fecal Enterococci Ds	222.4	54	510	124.48	11.8	0	38	10.48	94.69	-	1.27

Legend: Rs = Rainy season; Ds = Dry season; *E. coli* = Escherichia coli; A value of 1 CFU was assigned to each parameter whose germ count after treatment is = 0 CFU for the calculation of the LRV. Source: Data processing results.

The results of analyses performed 24 hours after water treatment using one Aquatab tablet per 20 liters of raw water demonstrate that this household disinfection method is 100% effective in eliminating microorganisms in samples with moderate (5 to 10 CFU/100mL) to medium (10 to 100 CFU/100mL) bacterial

loads, particularly when the water shows high clarity (turbidity below 3 NTU). Nonetheless, some microorganisms, including presumptive coliforms and thermotolerant coliforms, were detected in treated water, with average concentrations of 34 and 24 CFU/100mL, respectively. This presence may be attributed to the high microbial load in the raw water, elevated turbidity, and an insufficient dose of the disinfectant (specifically, using one 67 mg Aquatab tablet containing 60% active chlorine to treat 20 liters of water). These findings are consistent with results reported in previous studies [45]-[47] regarding water treatment with Aquatab tablets. The recommended dosage for unprotected water sources is two tablets per 20 liters, or one tablet per 10 liters. These dosages have also been applied in other study areas, as noted in [48] and [49]. However, around 80 % of households lack accuracy in measuring the volume of water treated with one Aquatab tablet often applying the tablet to more than 10 liters of water, especially when sourced from non-conventional supplies. Additionally, key practices such as turbidity reduction through decantation and hygiene measures (e.g., washing hands and containers with soap) are not followed in 80% of households. Disinfection protocols vary between households, and the presence of pathogens in treated water continues to increase a health risk (Figure 3).

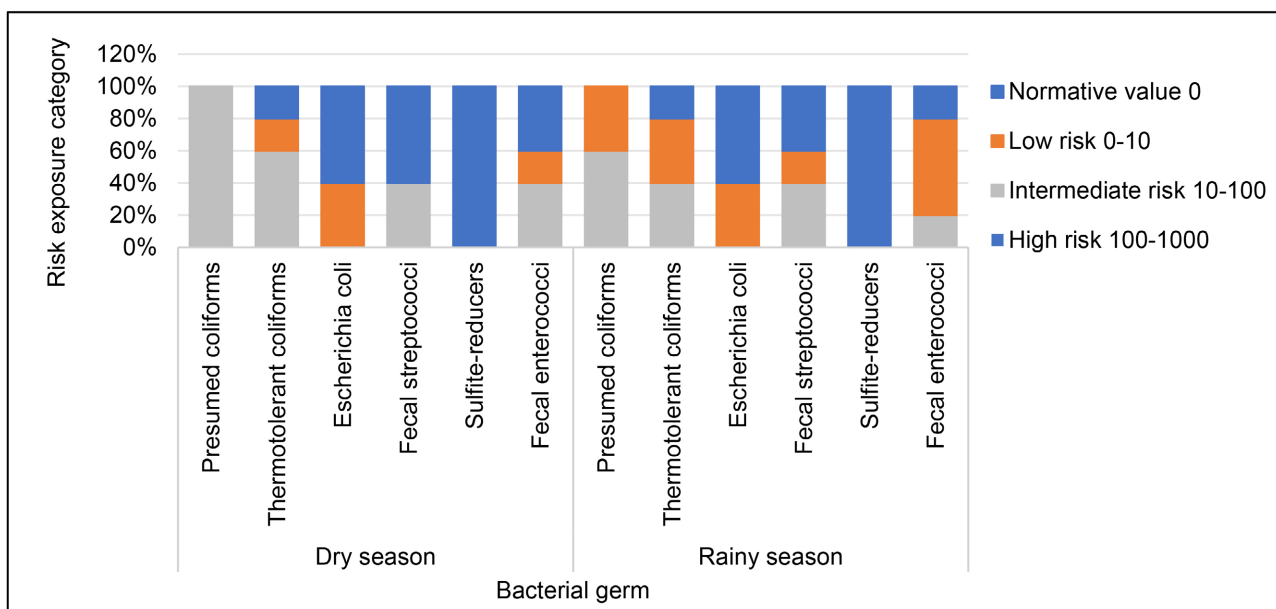


Figure 3. Risk category of consumer exposure to bacteria contained in water.

Water disinfection by Aquatab, carried out by households in the districts of Kandi, exposes people much less to the risks of diseases, in particular those that can be caused by *Escherichia coli* ( $\leq 40\%$ ), fecal enterococci ( $\leq 60\%$ ), thermotolerant coliforms ( $\leq 40\%$ ), and fecal streptococci ( $\leq 40\%$ ). The use of Aquatab tablets, although less restrictive, requires control of certain points, in particular the physical quality and the volume of water to be treated, in order to avoid incomplete treatment and exposure to the risks of diarrheal diseases.

### 3.1.2. Treatment of Well Water with Javel Water (Sodium Hypochlorite, Single Chlorination)

The decontamination of well water by sodium hypochlorite, commonly called Javel water, is a practice used by 61% of the households (21% at the beginning of the rainy season and 40% during the rainy season). This practice consists of adding liquid chlorine (sodium hypochlorite) to the well water. The evolution of the CR (Table 4) in these waters was recorded in each well.

**Table 4.** Evolution of residual chlorine (RC) on the wells treated with Javel water.

Well (W)	Well type	Turbidity (UNT)	pH	CR T0	CR T1	CR D1	CR D2	CR D3
W 21: Bapkara	LW	1.1	6.07	0	0.98	0.15	0.05	0
W 22: Gansosso	UW	5.1	6.20	0	0.20	0.1	0	0
W 33: Madina	LW	4	6.50	0	0.27	0.16	0	0
W 24: Zongo	LW	2.1	6.20	0	0.33	0.18	0.02	0
W 25: Keferi 2	UW	5.3	6.9	0	0.12	0.10	0	0
W 26: Baobab	UW	6.5	6.7	0	0.28	0.14	0	0

Legend: UW = unlined well; LW = lined well; T0 = time 0 before chlorination, T1 = 1 hour after chlorination; D1, D2 and D3 = Respectively day 1, day 2 and day 3 after chlorination. Source: Data processing results.

Among six distinct wells treated with a single dose of 1.5 liters of 2.6% sodium hypochlorite solution (Javel water), none exhibited an adequate residual chlorine level ( $\geq 0.3$  mg/L) 48 hours post-treatment (CRJ 2). The measured residual chlorine concentrations ranged from 0 to 0.02 mg/L. These low levels are likely attributable to high microbial loads and insufficient chlorine dosing, compounded by elevated turbidity levels particularly in wells lacking protective nozzles. Overall, the direct application of sodium hypochlorite for well disinfection does not appear to be an effective long-term solution at the household level. Nevertheless, this practice is officially recommended by hygiene authorities to assist households in mitigating waterborne disease risks during the rainy season in Kandi. Many households rely on well disinfection for up to three months, or throughout the entire rainy period. Temporal variations in residual chlorine levels (T1) and over consecutive days (D1) following chlorination are indicative of chlorine activity being inhibited. According to [3] and [17], for clear water, only a few milligrams per liter of free chlorine with approximately 30 minutes of contact time is sufficient to inactivate over 99.99% of enteric bacteria and viruses. In contrast, the presence of turbidity and organic matter can inhibit chlorine efficacy, allowing microbial survival and protection [50]. These findings are consistent with those of [51], who observed that in a sample of 10 wells treated with a single dose Javel water, only three maintained adequate residual chlorine for one day, while six never reached acceptable levels. It is important to underline concerning this direct water treatment in the well that the retention of the residual chlorine depend also

on the groundwater flow speed on the capted reservoir.

### 3.1.3. Treatment of Well Water by Boiling in Households

This alternative is largely practiced by the baby minder, who received instructions from a health worker in the process of treating children prone to diarrheal or dermatological diseases, and generally for a short time period. **Table 5** presents the variation of microbiological germs in boiling water.

**Table 5.** Variations in microbiological parameters on the boiled well water.

Settings	Raw water				Treated water by boiling				Reduction		
	Average	Min	Max	Standard deviation	Average	Min	Max	Standard deviation	Efficiency	Average LRV	LRV
Presumed coliforms Rs	1260	1020	373,000	253.33	0	0	0	-	100		5.20
Presumed coliforms Ds	122,527	1254	336,000	142,777	0	0	0	-	100	0.2	5.78
Thermo-tolerant coliform Rs	11,248	6466	21,408	4064	0	0	0	-	100	0.2	4.75
Thermo-tolerant coliform Ds	16,979	8404	33,914	8301	2	0	10	3.12	99.98	-	4.92
<i>E. coli</i> Rs	2313	31	6022	2198	0	0	0	-	100	0.2	4.14
<i>E. coli</i> Ds	3070	10	4209	1530	0	0	0	-	100	0.2	4.18
Fecal streptococci Rs	407.8	101	760	262	0	0	0	-	100	0.2	3.30
Fecal streptococci Ds	312.8	59	729	200	0	0	0	-	100	0.2	3.19
Sulfite Reducers Rs	5.6	0	14	6272	0	0	0	-	100	0.2	1.44
Sulfite Reducers Ds	1.2	0	6	1292	0	0	0	-	100	0.2	0.77
Fecal Enterococci Rs	241.8	21	519	201.76	1.4	0	7	2.24	99.09	-	2041
Fecal Enterococci Ds	180.8	19	378	130.96	0	0	0	0	100	0.2	2.17

Legend: see **Table 3**. Source: Data processing results.

Bacteriological analysis of the boiled water revealed the absence of coliforms, *Escherichia coli*, streptococci, and sulfite-reducing bacteria. For these Bacterial pollutants, the treatment efficiency reached 100%, with the LRVs ranging from 0.77 to 5.78 log<sub>10</sub>. However, enterococci were still detected at low concentrations in 40% of the treated water. The average counts during the rainy and dry seasons were respectively 2.67 CFU and 1.92 CFU. The presence of enterococci in boiled water may be attributed either to the post-treatment addition of unboiled well water (observed in 20% of households), intended to accelerate cooling and improve palatability. It can also be attributed to poor hygiene practices during water handling, such as leaving the water uncovered in basins and using cups handled by both children and adults without proper sanitation measures. In all sampled

households (100%), boiled water was poured into open basins for cooling before being transferred into plastic storage containers. As noted by [5] [52] [53] and [54], boiled water can become re-contaminated during the cooling and storage phases if appropriate precautions are not taken. Also, according to [55], among the 98.1% of households that boiled their water before drinking it, 25.9% still faced an average risk of *E. coli* presence. This includes ensuring that storage containers are properly cleaned and disinfected and protected from external contaminants.

Within the context of this study, the lack of hygienic handling practices likely contributed to the reappearance of enterococci in 40% of the stored water samples. Nevertheless, the health risk associated with the consumption of this water remains low, as microbial counts after boiling ranged between 7 and 10 CFU values that fall within the “low-risk” category (0 - 10 CFU) for waterborne disease transmission.

### 3.2. Implementation of Continuous Chlorination Practices and Use of Ceramic Filters

#### 3.2.1. Water Treatment by Continuous Chlorination

Continuous chlorination of well water using the calcium hypochlorite ( $\text{Ca}(\text{OCl})_2$ ) diffuser disposals helped to considerably reduce (Table 6) or even completely eliminate germs in treated wells.

**Table 6.** Variations in microbiological parameters on the water treated by the continuous chlorination techniques.

Bacteriological parameters	Before intervention				After intervention				Efficiency	Average LRV	LRV
	Average	Min	Max	Standard deviation	Average	Min	Max	Standard deviation			
Presumed coliforms Rs	125,296	11,040	562,000	174,681	144.6	0	700	310.63	99.85	-	2.82
Presumed coliforms Ds	124,139	6011	570,000	178,344	12	0	40	17.8	99.99	-	4.01
Coliform Thermo tolerant Rs	89417.2	5209	411,700	128,913	5.6	0	18	8.17	99.98	-	4.20
Coliform Thermo tolerant Ds	106,008	8760	483,200	150,876	3.2	0	10	4.60	99.99	-	4.5
<i>E. coli</i> Rs	5274	2320	8200	1980	0.6	0	2	0.891	99.98	-	3.72
<i>E. coli</i> Ds	4692	2000	9044	2036	0	0	0	0	99.99	-	4.06
Fecal streptococci Ds	2350.4	278	4233	1375	0	0	0	0	100	0.2	4.07
Fecal streptococci Rs	1813.2	156	4098	1256	0	0	0	0	100	0.2	3.91
Sulfite Reducers Rs	8.8	0	23	7	0	0	0	0	100	0.2	1.64
Sulfite Reducers Ds	1	1	1	0	0	0	0	0	-	-	-
Fecal Enterococci Rs	239	20	915	270	2.4	0	8	3.57	98.41	-	1.79
Fecal Enterococci Ds	139.4	19	670	172	1	0	4	1.73	99.04	-	2.02

Source: Data processing result.

The efficiency rates varied between 98.04 and 100% and the LRVs between 2 and 4  $\log_{10}$ . Fecal streptococci and sulfite reducers were eliminated in 100% of the wells; both in the rainy season and in the dry season. *E. coli* was only eliminated in the dry season. The continuous chlorination reduced the number of coliforms by 99.85% (rainy period) and 99.99% (dry period) in the majority of treated wells. Some wells (40%) presented, after 28 days of treatment, coliform values higher than zero per hundred milliliters (the WHO guideline value for drinking water). These results are similar to those of [19] who obtained non-conformities with regard to total coliform loads in eleven samples subjected to the continuous action of calcium hypochlorite. According to these authors, the observed non-conformities are linked to an insufficiency of chlorine necessary for the total disinfection of the treated water. In the period of 28 days of treatment of the experimental wells in Kandi, residual chlorine values were detected from the 2nd day until the 21st days (Figure 4) for all wells (values between 3 mg/L and 0.02 mg/L); beyond the 21st day, only 20% of wells showed residual chlorine (0.01 mg/L).

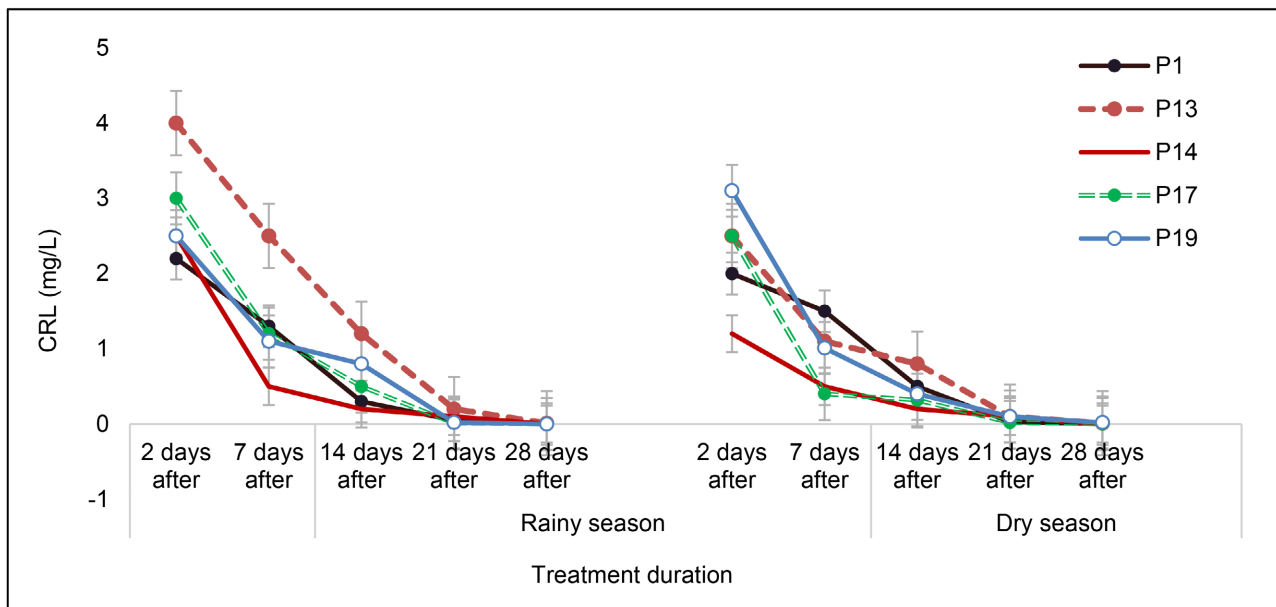


Figure 4. Variation in the concentration of free chlorine in the experimental wells.

By the 28th day after treatment, residual chlorine levels had dropped to zero in 80% of the monitored wells, while 40% of these wells still showed detectable concentrations of presumed coliform bacteria.

These findings suggest that a single application of 400 mg of calcium hypochlorite can maintain effective disinfection for about one month. Furthermore, [56] reported that the use of chlorine tablets in wells resulted in residual chlorine being present for approximately four weeks (28 days) in most treated wells, although there was a gradual decrease in residual chlorine (CR) after the first week. In contrast, [57] found that his proposed diffuser maintained effective and non-toxic CR levels for only three days. Bacterial concentrations after 28 days were

notably higher during the rainy season than in the dry season. This indicates that infiltration of surface water, likely contaminated by nearby latrines, refuse dumps, and other environmental sources, plays a significant role in degrading well water quality. Moreover, [58]-[60] and [61] evoked the influence of the precipitation events on coliform presence in groundwater. So [62]-[65] explain that the rainfall facilitates the transport of coliforms from surface environments into wells.

Regarding health risks, 40% of the wells fell into the low-risk category (0 - 10 CFU) during the dry season and 40% into the high-risk category (10 - 100 CFU) during the rainy season, indicating increased microbial contamination and potential exposure during the heavy rainfall events.

### 3.2.2. Water Purification Intervention with Ceramic Filters

After filtration, the microbiological quality of the treated water changed considerably as illustrated by **Table 7**.

**Table 7.** Variations in microbiological parameters on the water purified with ceramic filters.

Bacteriological parameters	Raw water				Filtered water by ceramic						
	Average	Min	Max	Standard deviation	Max	Min	Average	Standard deviation	Efficiency	Average	LRV
Presumed Coliforms Rs	315,288	13,000	671,000	245049.6	240	0	105.6	240	99.93	-	3.19
Presumed Coliforms Ds	186,534	6011	622,000	211172.8	83	0	34.4	43.2	99.98	-	3.71
Thermo-tolerant coliforms Rs	135706.8	1741	339,220	147725.36	1	0	0.2	1.6	99.99	-	5.13
Thermo-tolerant coliforms Ds	285,747	11,400	594,839	223,178	0.9	0	0.18	18.88	99.99	-	4.38
<i>E. coli</i> Rs	19071.6	458	59,000	15982.72	0.1	0	0.02	-	100	0.2	5.28
<i>E. coli</i> Ds	13924	513	42,822	13714.4	0.1	0	0.02	-	100	0.2	5.14
Fecal streptococci Rs	5196.8	302	9180	3166.24	0.1	0	0.02	-	100	0.2	4.71
Fecal streptococci Ds	3116.4	295	7699	1833.04	0.1	0	0.02	-	100	0.2	4.49
Sulfito-Reducers Ds	18.4	6	29	7.52	0.1	0	0.02	-	100	0.2	2.26
Sulfito-Reducers Rs	6.8	0	16	5.76	0	0	0	-	100	0.2	1.83
Fecal Enterococci Ds	389	79	948	323.2	3	0	1	-	100	0.2	3.28
Fecal Enterococci Rs	276.2	71	720	227.84	2	0	0.4	-	100	0.2	3.14

Legend: see **Table 3**; Source: Water analysis results.

The filtered water samples analyses revealed the complete absence of key microbiological indicators including *Escherichia coli*, *Streptococci*, sulfite-reducing bacteria, and *Enterococci*, with the LRVs ranging from 2 to 5 log<sub>10</sub>. [66] also reported complete removal of microbial contaminants particularly *E. coli* and *Strep-*

*tococci* following filtration using similar ceramic filters. Likewise, several studies [67]-[71] reported high removal efficiencies for *E. coli*, exceeding 98% and LRVs ranging between 2 and 7 log<sub>10</sub> [72]. However, total coliforms were still detected in 40% of the filtered water samples, with concentrations up to 200 CFU/100mL during the rainy season and up to 36 CFU/100mL during the dry season. This residual presence suggests suboptimal filtration performance, potentially due to design flaws such as filter pore sizes exceeding 0.45 µm. [73] also detected coliforms in filtered water. Nevertheless, in 60% of the filters tested, total coliforms were completely eliminated, indicating that some filters had pore sizes small enough to retain even the eggs and larvae of microorganisms absent in the effluents. These results contrast [22] and [73], who reported no coliform contamination in the effluents of all filters tested. Additionally, [16] [65], and [74] have demonstrated the high efficiency of ceramic filters in reducing bacterial contamination.

However, the performance of these filters can be inconsistent and non-durable, varying from one unit to another and across different geographic contexts. Clearly, ceramic filtering technology presents less risk to health. In 80% of filters, the purification efficiency is better because the filtered water contains less residue and remains clearer. Visible turbidity reduces the acceptability of drinking water in households [3] because it remains the first aspect of judging the quality of the water or its source. Many consumers associate turbidity with health safety and consider cloudy water to be unfit for consumption.

### 3.3. Effectiveness of the Different Treatment Techniques Followed and Experienced

A comparative analysis of the implemented methods of treating well water (Figure 5) during shows that: the use of ceramic filters and boiling gave very good performance (100% for all the germs sought). Nevertheless, it should be noted that the lack of hygiene on the part of households, favors recontamination of treated water, including heated water mixed with untreated water, in order to facilitate the cooling of the heated water.

Continuous chlorination on the wells using the diffuser pots performs similarly to boiling and ceramic filters; however, the risk of water quality deterioration in treated wells is higher. This is because the equipment used for drawing, transporting, and storing water is still not completely free of germs. The underperformance of Aquatab tablets, as revealed by the survey, is mainly due to households not properly managing the treatment process.

These findings align with those of [75] comparative research on home water treatment methods, which showed that filtration removed coliforms and *E. coli* by 99.84% and 100%, respectively, while boiling removed 98% and 96%. The safe LRVs for filtration were 76.63% for coliforms and 100% for *E. coli*, compared to 40% and 96.36% for boiling. Notably, only home filtration showed no risk of infection, making it the most effective method for removing microorganisms from raw water.

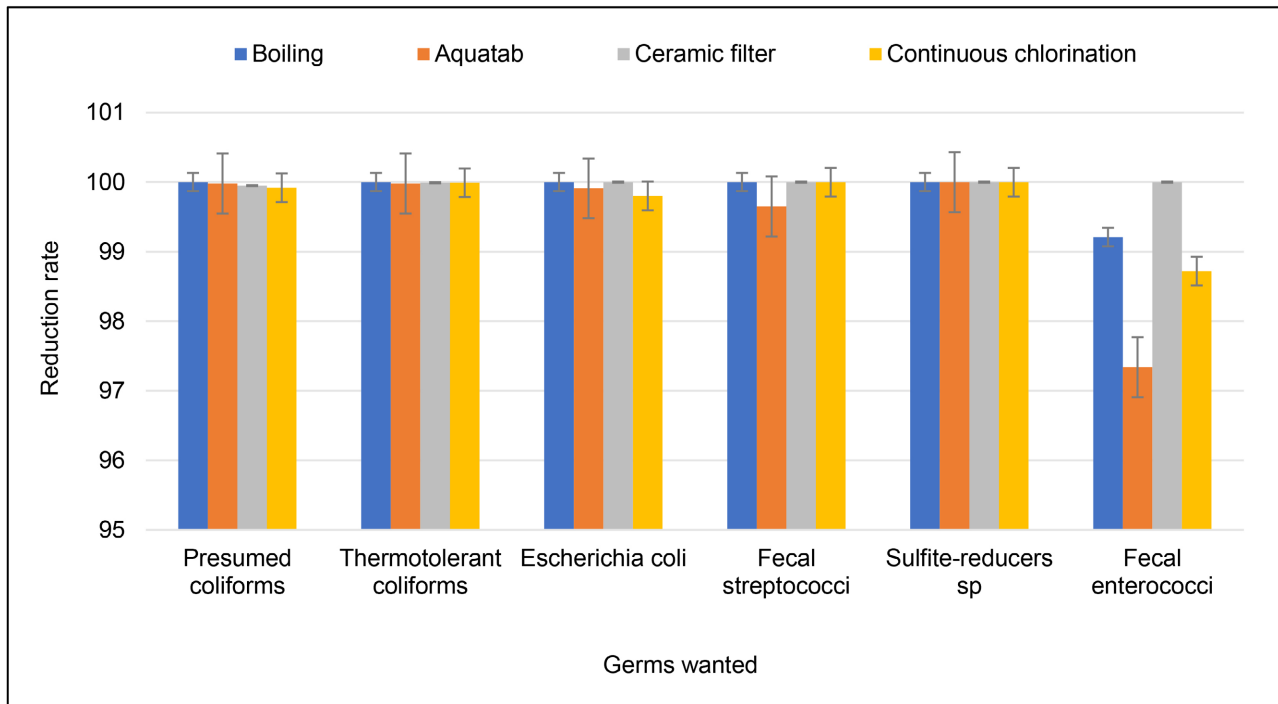


Figure 5. Bacterial pathogens elimination rate by treatment techniques.

### 3.4. HACCP Plan Applied to Water Treatment Methods

The synthesis of the study results interpreted with the HACCP plan is presented on Table 8.

Table 8. HACCP Pan applied to household water treatment methods in Kandi (Benin).

Purification methods	Observations	Identified dangers	CCP	Critical limit	Associated risks	Preventive/ Corrective measures	Responsible
Use Javel water	Use 1.5 liters of Javel water	1) Absence of CRL in the water after 24 hours 2) Risk of bacteriological contamination	1	10 CFU/ 100 ml	Consumer exposure to waterborne diseases	Replace this type of treatment with continuous chlorination	Head of household Water users Women
Boiling	1) Adding untreated water to boiled water 2) Exposure of water to the open air 3) Unhygienic containers	untreated water Presence of suspended matter Exposure of water to the open air and exchange of container after cooling	2	10 CFU/ 100 ml	1) Recontamination of water 2) Exposure of households to waterborne diseases	Let the water cool naturally Store water in a hygienic container and away from dust.	Baby minder Women

## Continued

Use of Aquatabs	1) Lack of control over container volumes 2) Container not washed with soap 3) Insufficient dosage of aquatab tablet	1) Incomplete water treatment 2) Presence of Presumed Fecal Streptococcus Coliforms and <i>E. coli</i> in treated water	3	10 CFU/100 ml	1) Waterborne disease	Used the graduated buckets, filtered the water to reduce turbidity, Review the doses of product used	Water users Women
Continuous chlorination	1) Variation of water level 2) Drowning of the chlorine diffuser pot resulting in diffusion of large quantities of chlorine 3) Removal of the pot from the well/ discontinuous treatment	1) Increased chlorine smell in the water 2) Presence of fecal coliforms and enterococci after 28 days	4	10 CFU/100 ml	1) Rejection of the treatment technique 2) Chlorine overdose 3) Incomplete water treatment if the CRL is absent (risk of waterborne disease)	1) Control of the variation of the static water level and adjustment of the diffuser pots in the well 2) Renew the contents of the diffuser pot after 4 to 5 weeks	Head of household
Filtration with ceramic filters	Complaint of low flow rate (2.1 L/h) of water at the filter outlet	1) Incomplete water treatment 2) Presence of coliform in treated water	5	10 CFU/100 ml	Consumer exposure to waterborne diseases	Draw designers' attention to the performance of certain filters	Filter concept

Source: Data processing results.

The most difficult risk factor to control is the lack of control over the implementation of treatment methods chosen by households. It is therefore necessary to review the procedures for implementing water treatment practices. A comparison between the WHO recommendations for drinking water treatment and the habits of households in the urban district of Kandi clearly shows treatment failures regardless of the treatment method chosen.

This could enable to develop water education to perform water treatment techniques and to sustainable safe drinking water in the current global environmental change in the developing countries.

#### 4. Conclusions

The findings indicate that all the wells investigated in the city of Kandi exhibit poor microbiological quality. Households assess water quality primarily through organoleptic characteristics such as clarity, color, and taste, and employ various treatment methods accordingly. Among these, sodium hypochlorite (Javel water) and Aquatabs are the most commonly used disinfection products. Monitoring of

household water treatment practices including Javel water use, boiling, and Aquatab usage revealed several shortcomings, particularly in dosage application at both the point of use (Aquatabs, boiling) and at the water source (Javel water).

Among the treatment methods tested, continuous chlorination using calcium hypochlorite ( $\text{Ca}(\text{OCl})_2$ ) diffuser pots demonstrated the most effective results, achieving complete microbial removal for up to 28 days when 400 grams of granular chlorine were applied. Specifically, 60% of wells showed total elimination of thermotolerant coliforms, *Escherichia coli*, fecal Streptococci, sulfite-reducing bacteria, and fecal Enterococci for at least 21 days. Disinfection efficiency ranged from 98.04% to 100%, with the LRVs between 1.64 and 4.07  $\log_{10}$ . Additionally, 100% of these wells met WHO standards for pH, and 80% met the standards for turbidity. Filtration using ceramic filters demonstrated high purification efficiency in 80% of the filters, with minimal residual contamination. However, analysis of the filtered water revealed design flaws in some filters (2 out of 5), suggesting inconsistency in performance. Nevertheless, the risk of exposure to water-borne pathogens remained low fewer than 10 CFU/100mL for water treated by ceramic filtration, boiling, or chlorination by diffuser pots. A multi-barrier approach [71] encompassing source water protection, effective treatment, and safe water storage remains the most reliable strategy for ensuring microbiologically safe drinking water.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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