International Journal of Nutrition and Food Sciences
2024, Vol. 13, No. 3, pp. 102-113
https://doi.org/10.11648/j.ijnfs.20241303.15

SciencePG
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Research Article

Quality Control of Tap Water and Factors Determining Bacterial Contamination of Households' Stored Drinking Water in the Town of Aboisso (Côte d'Ivoire)

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Abstract

Piped water must inspire consumer confidence in health and organoleptic terms. In the event of a food poisoning, consumers who have a poor perception of its quality may incriminate it, without taking into consideration that the fact of passing it through a drinking water storage container before consuming it can also cause contamination. The present study carried out in the town of Aboisso aimed to assess the role of water storage in the deterioration of microbiological quality of drinking water, and to identify the predictive factors of the presence of bacteria in stored water. To do this, physicochemical parameters (temperature, pH, conductivity, turbidity and free chlorine) and microbiological parameters (total coliforms, thermotolerant coliforms and *E. coli*) were measured on water samples taken from taps and storage containers in 94 households. The storage conditions of drinking water were also the subject of a brief household survey. The identification of predictive factors for the presence of total coliforms and *E. coli* in stored water was done using bivariate analysis and multivariate analysis by binary logistic regression through two models. The first model included the use of a transport container and the storage conditions as independent variables. The second included besides that the values of turbidity and free chlorine. As results, the waters were weakly mineralized and acidic. Free chlorine levels, temperature values, and bacterial loads in tap water were significantly ($p < 0.05$) higher than those in stored water. While 13.83% of samples taken at the taps were contaminated with total coliforms and 1.06% with *E. coli*, 50% and 18.09% of those taken in containers were contaminated with total coliforms and *E. coli*, respectively. In the first model, only the storage duration and the method used to draw water from storage container were statistically associated with the presence of total coliforms while no variable was statistically associated with the presence of *E. coli*. In the second model, the drawing method and the free chlorine level were significantly associated with the presence of total coliforms while only the free chlorine level was associated with *E. coli*. These results motivate the need to raise awareness and train populations in drinking water hygiene.

Keywords

Piped Water, Water Storage, Water Quality, Total Coliforms, *E. coli*, Multivariate Analysis, Logistic Regression

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Received: 15 April 2024; **Accepted:** 17 May 2024; **Published:** 3 June 2024

1. Introduction

Water is essential for the satisfaction of many daily personal and domestic needs: drinking, personal hygiene, cooking, washing dishes, laundry and toileting. When it is intended for drinking, it must be safe, otherwise it could cause water-borne diseases or even deaths [1]. In addition to be safe, it must be available in sufficient quantity, to avoid populations resorting to sources of questionable quality [2]. Having water of satisfactory quality and quantity is a right that contributes to better human well-being [3].

There are multiple sources of drinking water supply. However, it is recommended to drink water from improved sources such as public water or tap water, which are by definition less likely to be contaminated by faeces [4]. Indeed, tap water is a treated and controlled water that is transported via a network of pipes to consumers. It is the product of a set of simple or complex operations inflicted on raw water of underground or surface origin [5] with the aim of ensuring that it meets drinking water standards [6].

Despite tap water purification treatments, it may be rejected by consumers or be the subject of recurring complaints. This dissatisfaction may be due, among other reasons, to a poor perception of the quality of the raw water used to produce drinking water [7, 8], a poor perception of the quality of tap water [7], or a perception of health risks [9].

In Côte d'Ivoire, tap water is produced using surface and/or groundwater [10]. In the town of Aboisso, it is produced with the BIA river water. As mentioned by [11], this river is a receptacle for solid and liquid waste (wastewater) and a place of defecation for many. It would also be subject to pollution by clandestine gold panning and agriculture in Côte d'Ivoire and by mining activities in Ghana [12, 13]. This pollution of raw water resources observed or heard by households could give them a bad perception of tap water. Even if it is true that tap water can be subject to contamination at the source [14], several studies have demonstrated that microbiological contamination of tap water after collection, i.e. during transport, storage and handling was frequent [15, 16]. Water storage is an adaptation practice which is increasingly used to deal with problems of access to water and water availability [17] and which also allows time for turbid water to settle before drinking it [15].

Thus, the objective of this study was to compare the quality of drinking water at the tap and at the household storage container on the one hand, and to analyze the impact of storage conditions on the microbiological quality of stored drinking water on the other hand.

2. Materials and Methods

2.1. Study Area

The town of Aboisso is located in the southeast of Côte d'Ivoire, approximately between 5°40 and 5°50 north latitude and between 3°15 and 3°25 west longitude. It is the capital of the department of the same name and the capital of the Sud-Comoé Region. The climate is equatorial with two dry seasons and two rainy seasons. The town of Aboisso is crossed by the BIA river, 290 km long, whose source is located in Ghana. The water from this river is treated in a drinking water production plant before being used to supply the town with water. The treatment of raw water combines a physicochemical process (coagulation – flocculation - decantation using alumina sulfate), a physical process (slow filtration on sand) and chemical processes (neutralization with slaked lime and disinfection using calcium hypochlorite).

2.2. Data Collection

Data were collected during the dry season, from March to April 2022 through a household survey and physicochemical and microbiological analyzes of water samples in ninety-four (94) households. Households were chosen randomly from those with taps at home and storing tap water intended for drinking.

2.2.1. Household Survey

A household questionnaire developed on Google Forms was administered to households by direct interview using smartphones. The questionnaire was filled in as the interview progressed and the data stored online. The survey method combined field observations with interviews. The questions focused on the date of stored water collection, the characteristics of the storage container, the storage conditions, the treatment of the stored water and the method for drawing the water from storage container.

2.2.2. Physicochemical and Microbiological Samples and Analyzes

The parameters measured on the samples were conductivity, pH, turbidity, temperature, free chlorine, total coliforms, thermotolerant coliforms and *E. coli*. Conductivity, pH, turbidity, temperature and free chlorine were measured on site. The pH measurement was done by electrochemical glass electrode method using a HANNA® HI 991003 pH meter. Conductivity and temperature were measured using a HANNA® HI 98192 conductivity meter by the titanium electrode electrochemical method. Turbidity was measured with a HANNA® HI 98713 turbidimeter using the nephelometric method. Free chlorine was determined using a Palintest 7100 photometer by the DPD (N, N-Diethyl-p-phenylenediamine) method.

Microbiological analyzes were carried out in the laboratory. In each household, two water samples were collected in 500 ml borosilicate glass vials containing thiosulfate, one from the tap and the other from the storage container. The samples were stored away from light in coolers containing eutectic plates allowing the temperature to be maintained at around 4°C. Coliforms (total, thermotolerant and *E. coli*) were detected by the membrane filtration method according to standard NF EN ISO 9308-1. To do this, homogeneous aliquots of 100 ml were filtered through membranes with a pore diameter of 0.45 µm. The membranes were then placed on a culture medium based on RAPID'E.coli 2 agar in petri dishes with a diameter of 55 mm. These plates were incubated in an incubator at 37 ℃ for 24 hours for coliforms and *E. coli* and in an incubator at 44 ℃ for 48 hours for thermotolerant coliforms. The microbiological analyzes were carried out within 4 hours after samples collection.

2.3. Data Analysis

Microsoft Excel 2016 software was used to calculate basic descriptive statistics (minimum, median, mean ± standard deviation, maximum, coefficient of variation) and percentages of non-compliance of water quality parameters.

The RStudio software version 2023.03.0 for Windows was used to compare the quality of water at the tap and that of stored water through each parameter. For this purpose, boxplots and Wilcoxon rank sum test at the 5% threshold were used. Wilcoxon test was chosen due to non-compliance with the conditions for applying the Student test (normality and equality of variances). RStudio was also used to identify, through a bivariate analysis, the variables that had a link with the presence in stored water of total coliforms on one side and *E. coli* on the other. Then, a binary logistic regression was used to study the influence of storage conditions on the one hand, and storage conditions, free chlorine and turbidity values on the other, on contamination of stored water by total coliforms and *E. coli*. The conditions of validity of the models (linearity of the model, independence of the residuals, no multicollinearity and no aberrant effects) were also checked.

3. Results

3.1. Water Quality at Taps and Storage Containers

Concerning the water samples taken from taps, no sample complied with the Ivorian standard. The non-compliances mainly concerned physicochemical parameters such as conductivity, pH, turbidity, and to a lesser extent free chlorine. Indeed, 100% of the samples had a conductivity lower than 200 µS/cm, 98.94% had a pH lower than 6.5 and 95.74% had a turbidity higher than 1 NTU. These waters were therefore acidic and weakly mineralized. Microbiological contamination was marked by the presence of total coliforms in 13.83% of the samples. The coefficient of variation (CV) values were less than 0.15 for temperature, pH and conductivity, indicating that only these parameters showed homogeneous values (Table 1).

Regarding the storage containers, none of the water samples taken from them complied with the Ivorian standard either. The physicochemical non-compliances were due in order of importance to conductivity (100%), pH (98.94%), turbidity (76.60%) and free chlorine (71.28%). Microbiological contamination by total coliforms affected 50% of the samples and the presence of *E. coli*, an indicator of fecal contamination, was observed in 18.09% of the samples. Temperature, pH and conductivity had homogeneous values with regard to the values of the coefficient of variation (Table 2).

Comparison between the quality of tap samples and stored water samples showed a significant difference in temperature, turbidity, free chlorine and microbiological parameters (Figures 1A, 1D, 2A, 2B, 2C and 2D).

Table 1. *Descriptive statistics of tap water quality.*

Parameters	Units	Min	Med	Mean ± SD	Max	CV	Ivorian standard	Non-compliances	
								n	%
Temp	℃	26.50	30.00	30.02 ± 1.50	33.20	0.05	-		-
pH*	-	5.62	5.97	5.98 ± 0.19	6.56	0.03	$6.5 \leq pH \leq 9$	93	98.94
Cond*	µS/cm	107.1	121.80	122.35 ± 8.23	143.3	0.07	$200 \leq Cond \leq 1100$	94	100
Turb	NTU	0.45	1.91	2.15 ± 1.01	6.42	0.47	Turb ≤ 1	90	95.74
Cl_2*	mg/l	0.03	0.89	0.86 ± 0.44	2.20	0.52	$0.2 \leq Cl_2 \leq 1$	38	40.43
T C	CFU/100 ml	0	0	47.20 ± 392.98	3800	8.33	< 1	13	13.83
Th C	CFU/100 ml	0	0	0.20 ± 1.96	19	9.70	< 1	1	1.06
E. coli	CFU/100 ml	0	0	0.20 ± 1.96	19	9.70	< 1	1	1.06

Temp = Temperature, Cond = Conductivity, Turb = Turbidity, Cl_2 = Free chlorine, T C = Total coliforms, Th C = Thermotolerant coliforms, Min = Minimum, Med = Median, SD = Standard deviation, Max = Maximum, CV = Coefficient of variation
*n = 93 (98.94%) for pH < 6.5; n = 94 (100%) for Cond < 200 µS/cm; n = 6 (6.38%) for Cl_2 < 0.2 mg/l; n = 32 (34.04%) for Cl_2 > 1 mg/l

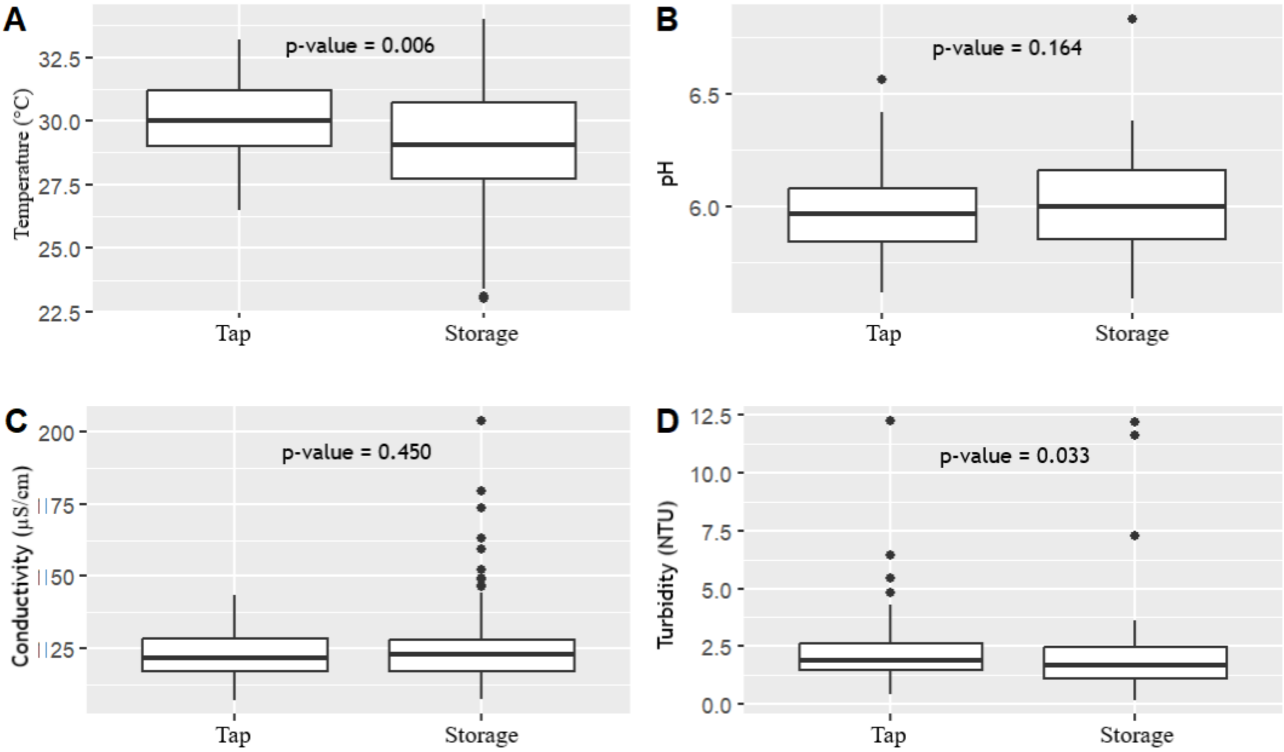

Figure 1. *Comparison between tap water and stored water in terms of temperature, pH, conductivity and turbidity (Wilcoxon rank sum test p-value for α =5%).*

Table 2. *Descriptive statistics of stored water quality.*

Parameters	Units	Min	Med	Mean ± SD	Max	CV	Ivorian standard	Non-compliances	
								n	%
Temp	℃	25.40	29.05	29.44 ± 1.86	34	0.06	-	-	-
pH*	-	5.59	6.00	6.02 ± 0.21	6.83	0.04	$6.5 \leq pH \leq 9$	93	98.94
Cond*	µS/cm	107.30	122.85	125.69 ± 13.77	179.5	0.11	$200 \leq Cond \leq 1100$	94	100
Turb	NTU	0.18	1.71	1.89 ± 1.21	7.27	0.64	Turb ≤ 1	72	76.60
Cl_2*	mg/l	0	0.120	0.30 ± 0.39	1.83	1.30	$0.2 \leq Cl_2 \leq 1$	67	71.28
C T	CFU/100 ml	0	0.50	725.83 ± 1218.01	4900	1.68	< 1	47	50.00
Th C	CFU/100 ml	0	0	48.23 ± 291.65	2600	6.05	< 1	17	18.09
E. coli	CFU/100 ml	0	0	39.18 ± 233.68	2080	5.96	< 1	17	18.09

Temp = Temperature, Cond = Conductivity, Turb = Turbidity, Cl_2 = Free chlorine, T C = Total coliforms, Th C = Thermotolerant coliforms, Min = Minimum, Med = Median, SD = Standard deviation, Max = Maximum, CV = Coefficient of variation
*n = 93 (98.94%) for pH < 6.5; n = 94 (100%) for Cond < 200 µS/cm; n = 59 (62.77%) for Cl_2 < 0.2 mg/l; n = 8 (8.51%) for Cl_2 > 1 mg/l

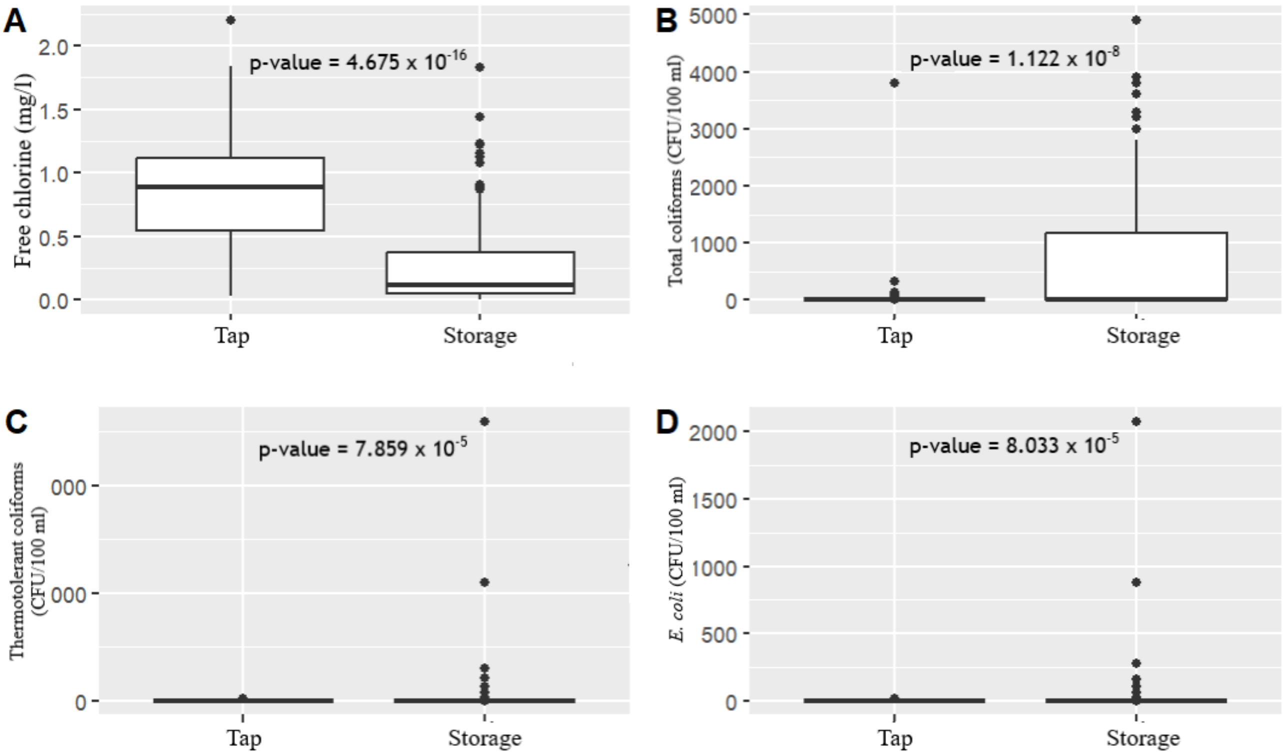

Figure 2. *Comparison between tap water and stored water in terms of free chlorine, total coliforms, thermotolerant coliforms and E. coli (Wilcoxon rank sum test p-value for α =5%).*

3.2. Factors Associated with the Microbiological Quality of Stored Water

Bivariate analysis (p-value < 0.05) showed that storage duration, drawing method, turbidity and free chlorine level as the variables those had a link with the presence of total coliforms. Only the drawing method and the level of free chlorine were associated with *E. coli* (Table 3).

In binary logistic regression, two models (model 1 and model 2) were generated to determine the explanatory factors for the occurrence of bacterial contamination of stored water. Model 1 only analyzed the influence of variables relating to the use of a transport container and storage conditions on bacterial contamination of water while model 2 studied the combined effect of the use of a transport container, storage conditions, turbidity and free chlorine. A step-by-step descending selection made it possible to select the most relevant variables in each model.

Concerning total coliforms (Table 4), in model 1, storage duration and drawing method appeared as two risk factors significantly linked to their presence. Indeed, according to this model, households which stored their water for more than 2 days (OR = 5.47; p-value = 0.021) and those which used a vessel with a handle (OR = 3.50; p-value = 0.045) had respectively 5.47 times and 3.5 times greater risk of having total coliforms in their waters. In model 2, the use of a vessel without handle as a method for drawing water appeared to be a protective factor (OR = 0.09; p-value < 0.05). On the other hand, a free chlorine level below 0.2 mg/l (OR = 12.0; p-value < 0.001) represented a risk factor. Model 2 showed that households using a vessel without handle were 10 times less likely to have contaminated water and those whose chlorine level was less than 0.2 mg/l were 12 times more likely to have contaminated water.

Concerning *E. coli*, due to significant errors in the estimation of the models due to the low number of certain modalities of the "drawing method" variable, this was excluded from the models. Model 1 did not highlight any variable having a significant effect at the threshold α = 5%. In model 2, free chlorine level was the only variable that explained the presence of *E. coli* in stored water. Indeed, this model estimated that stored water which contained a chlorine level lower than 0.2 mg/l had a 16.7 times greater risk of containing *E. coli* (Table 5).

***Table 1**. Bivariate analysis of the link between various variables and the presence of total coliforms and E. coli in stored water (p-value of Chi-square test, α = 5%).*

variables	Total N = 94	Total coliforms			*E. coli*		
		Absence N = 47	Presence N = 47	p-value	Absence N = 77	Presence N = 17	p-value
Storage duration				0.016			>0.9
Two days and less	77	55.8%	44.2%		81.8%	18.2%	
More than two days	17	23.5%	76.5%		82.4%	17.6%	
Use of a transport container				0.5			0.3
No	61	52.5%	47.5%		78.7%	21.3%	
Yes	33	45.5%	54.5%		87.9%	12.1%	
Storage container volume				0.4			0.5
≤ 20 litres	68	52.9%	47.1%		83.8%	16.2%	
> 20 litres	26	42.3%	57.7%		76.9%	23.1%	
Storage container storage location				>0.9			0.7
In the House	78	50.0%	50.0%		80.8%	19.2%	
Outside the house	16	50.0%	50.0%		87.5%	12.5%	
Storage container properly covered				0.8			0.055
Yes	81	50.6%	49.4%		85.2%	14.8%	
No	13	46.2%	53.8%		61.5%	38.5%	
Presence of deposit in the storage container				0.090			0.2
No	36	61.1%	38.9%		88.9%	11.1%	
Yes	58	43.1%	56.9%		77.6%	22.4%	
Drawing method				0.004			0.002
Pour out from container	20	70.0%	30.0%		100.0%	0.0%	
Dip vessel with handle into container	63	38.1%	61.9%		73.0%	27.0%	
Dip vessel without handle into container	11	81.8%	18.2%		100.0%	0.0%	
Turbidity				0.003			0.2
≤ 1 NTU	22	22.7%	77.3%		72.7%	27.3%	
> 1 NTU	72	58.3%	41.7%		84.7%	15.3%	
Free chlorine level				<0.001			0.003
$Cl_2 \geq 0.2$ mg/l	35	82.9%	17.1%		97.1%	2.9%	
$Cl_2 < 0.2$ mg/l	59	30.5%	69.5%		72.9%	27.1%	

***Table 4**. Logistic regression between various variables and the presence of total coliforms in stored water (p-value of Chi-square, α = 5%).*

Variables	Model 1			Model 2		
	OR	95% IC	p-value	OR	95% IC	p-value
(Intercept)	0.30	0.09 – 0.85	0.031	0.20	0.03 – 1.28	0.10

	Model 1			Model 2		
Variables	**OR**	**95% IC**	**p-value**	**OR**	**95% IC**	**p-value**
Storage duration						
Two days and less	1.00	—		1.00	—	
More than two days	5.47	1.44 – 28.0	0.021	3.00	0.68 – 17.2	0.2
Use of a transport container						
No	1.00	—		1.00	—	
Yes	0.89	0.32 – 2.46	0.8	0.76	0.24 – 2.36	0.6
Storage container volume						
≤ 20 liters	1.00	—		1.00	—	
> 20 liters	0.80	0.26 – 2.44	0.7	0.98	0.27 – 3.65	>0.9
Storage container storage location						
In the House	1.00	—		1.00	—	
Outside the house	1.09	0.28 – 4.42	0.9	2.17	0.41 – 11.9	0.4
Storage container Properly covered						
Yes	1.00	—		1.00	—	
No	1.33	0.34 – 5.61	0.7	1.20	0.23 – 7.07	0.8
Presence of deposit in the storage container						
No	1.00	—		1.00	—	
Yes	1.51	0.57 – 3.98	0.4	2.17	0.70 – 7.04	0.2
Drawing method						
Pour out from container	1.00	—		1.00	—	
Dip vessel with handle into container	3.50	1.07 – 12.7	0.045	1.21	0.26 – 5.46	0.8
Dip vessel without handle into container	0.28	0.03 – 2.06	0.2	0.09	0.01 – 0.81	0.046
Turbidity						
≤ 1 NTU				1.00	—	
> 1 NTU				0.45	0.11 – 1.69	0.2
Free chlorine level						
$Cl_2 \geq 0.2$ mg/l				1.00	—	
$Cl_2 < 0.2$ mg/l				12.0	3.66 – 46.5	<0.001

IC = Interval of Confidence, OR = Odds Ratio

***Table 5**. Logistic regression between various variables and the presence of E. coli in stored water (p-value of Chi-square, α = 5%).*

	Model 1			Model 2		
Variables	**OR**	**95% IC**	**p-value**	**OR**	**95% IC**	**p-value**
(Intercept)	0.12	0.03 – 0.34	<0.001	0.02	0.00 – 0.20	0.004
Storage duration						

	Model 1			Model 2		
Variables	**OR**	**95% IC**	**p-value**	**OR**	**95% IC**	**p-value**
Two days and less	1.00	—		1.00	—	
More than two days	0.94	0.18 – 3.91	>0.9	0.71	0.12 – 3.33	0.7
Use of a transport container						
No	1.00	—		1.00	—	
Yes	0.44	0.10 – 1.60	0.2	0.27	0.05 – 1.14	0.10
Storage container volume						
≤ 20 liters	1.00	—		1.00	—	
> 20 liters	2.00	0.51 – 7.82	0.3	2.56	0.54 – 12.9	0.2
Storage container storage location						
In the House	1.00	—		1.00	—	
Outside the house	0.43	0.05 – 2.20	0.4	0.44	0.04 – 2.95	0.4
Storage container Properly covered						
Yes	1.00	—		1.00	—	
No	2.71	0.67 – 10.2	0.14	3.24	0.67 – 16.1	0.14
Presence of deposit in the storage container						
No	1.00	—		1.00	—	
Yes	2.34	0.69 – 9.51	0.2	2.38	0.64 – 10.7	0.2
Turbidity						
≤ 1 NTU				1.00	—	
> 1 NTU				0.67	0.17 – 2.77	0.6
Free chlorine level						
$Cl_2 \geq 0.2$ mg/l				1.00	—	
$Cl_2 < 0.2$ mg/l				16.7	2.70 – 340	0.013

IC = Interval of Confidence, OR = Odds Ratio

4. Discussion

Public distribution water makes it possible to supply households, simultaneously and at the scale of one or more localities, via domestic taps. It is therefore imperative that it meets the quality requirements set by current drinking standards, because the occurrence of contamination could be catastrophic in terms of health. At the consumer's tap, its health and organoleptic quality must be impeccable. During and after the collection of water from the tap, this quality must be preserved and it is the responsibility of the consumer to take all measures to this effect.

In this study, the water quality parameters measured were temperature, pH, conductivity, turbidity, free chlorine, total coliforms, thermotolerant coliforms and *E. coli*.

The temperature of water collected from taps (30.02 ± 1.50) was significantly higher (p-value = 0.006) than that of stored water (29.44 ± 1.86). The water temperature at the time of sampling is closely controlled by the ambient temperature [18, 19]. Since taps and storage containers are at room temperature inside or outside homes, higher tap water temperatures could be explained by heating of water pipes by solar rays [20].

The pH of the tap water and that of the stored water were acidic (pH < 6.5) with homogeneous values (CV < 0.15). There was no significant difference between the pH values at the taps and those at the storage containers. The acidity of the water could indicate a need to adjust the water treatment. Indeed, while alumina sulfate causes a drop in the pH of the water [21], lime, like calcium hypochlorite, leads to an upward trend in the pH of the water [22, 23]. However, if it is assumed that the pH was well adjusted at the outlet of the treatment station, the acidity of the tap water could then be explained by the increase in temperature in the drinking water distribution pipes with resulting in a decrease in pH [19, 24].

The conductivity values measured at the taps, like those measured at the storage containers, were, like those of temperature and pH, homogeneous. The waters were weakly mineralized (Cond < 200 µS/cm) and did not meet the Ivorian standard. The non-significant difference between the conductivity of tap water and stored water thus indicated that they had not suffered the effects of contact with other materials.

The turbidity of the water at the tap was above the standard (1 NTU) for 95.74% of the samples. This could be due to the obsolescence of the town's water distribution network [25]. In addition, the turbidity of tap water (2.15 ± 1.01 NTU) was significantly higher than that of storage water (1.89 ± 1.21 NTU). This lower turbidity of stored water compared to tap water could be justified by the fact that during storage the suspended matter gradually settles, producing a clearer supernatant [26].

Concerning the free chlorine values, they were clearly and significantly lower (p-value = 4.675 x 10-16) in the stored water than in the tap water samples with respective means of 0.30 ± 0.39 mg/l and 0.86 ± 0.44 mg/l. These lower levels of free chlorine in storage containers could be attributed to one or a combination of factors such as the volatility of chlorine [27], its destruction by light [28, 29] and its consumption by chemical or biological pollutants [30, 31]. Thus, uncovered, transparent or translucent, unclean storage containers and unhygienic handling or use of water can induce a gradual drop in the free chlorine level until reaching a zero value.

In terms of microbiological quality, the loads of total coliforms, thermotolerant coliforms and *E. coli* were respectively 725.83 ± 1218.01 CFU/100 ml, 48.23 ± 291.65 CFU/100 ml and 39.18 ± 233.68 CFU/100 ml in stored water. These loads were significantly higher (p-value < 0.001) than in tap samples where they were 47.20 ± 392.98 CFU/100 ml for total coliforms, and 0.20 ± 1.96 CFU/100 ml for thermotolerant coliforms and *E. coli*.

Total coliforms are indicators of cleanliness and integrity of drinking water networks while *E. coli* (otherwise thermotolerant coliforms) is an indicator of recent fecal contamination. Their presence in water collected from the tap may be due to a failure of the water treatment system or to problems with the sealing or maintenance of the water distribution network [32]. The intermittent supply of drinking water may also be the cause of their presence [33]. The presence of coliforms of all types in stored water can be attributable to contamination at the time of collection, during transport, storage or handling at home [34, 35].

In the models (models 1) taking into account only the use of a transport container and the storage conditions as independent variables, the contamination of stored water by total coliforms was associated with storage water for more than two days (p-value = 0.021) and collecting water with a collecting water with a vessel with handle (p-value = 0.045). Thus, the microbiological quality of the water was more degraded for storage periods longer than two days. This result is in agreement with those of [36, 37] who showed that the microbiological quality of stored water decreases with increasing storage duration. Against all expectations, the use of a handled vessel appeared to be a risk factor even though authors such as [38] recommended it. This again poses the problem of hand hygiene and the cleanliness of utensils in contact with drinking water. For *E. coli*, the logistic regression did not significantly associate its presence with any of the risk factors studied.

Regarding models (models 2) integrating transport and storage conditions, free chlorine levels and water turbidity, the presence of total coliforms was significantly associated (p-value < 0.001) with a free chlorine level less than 0.2 mg/l as well as that of *E. coli* (p-value = 0.013). The use of a vessel without handle to draw water appeared here as a protective factor associated with the bacterial quality of the water (p-value = 0.046) while its use was prohibited by [38] who saw it as a risk factor for microbiological contamination of stored water. Despite these results, dipping any vessel into a drinking water storage container should be prohibited.

5. Conclusions

It is vitally important that public distribution water be of satisfactory organoleptic and health quality at the consumer's tap. In the present study carried out in the town of Aboisso, water quality control showed physicochemical non-conformities mainly related to pH, turbidity and conductivity. Fortunately, these parameters do not have direct or immediate effects on health. Regarding microbiology, the quality control of tap water revealed contamination by total coliforms at the tap (13.83%). At the level of storage containers, microbiological contamination was greater than at the tap, mainly due to post-collection handling. Indeed, in addition to a greater presence of total coliforms (50%), *E. coli* was present in 18.09% of the samples. Notwithstanding these cases of contamination of tap water and the poor perception of its quality, tap water remains relatively safer than many sources of drinking water, including all uncontrolled and untreated sources. Indeed, this study also objectified and reinforced chlorination as a preventive measure of protection against microbiological contamination of water to the extent that samples with a free chlorine level lower than 0.2 mg/l had a greater risk to be microbiologically contaminated. In any case, given these findings and the risks of water-borne diseases incurred, awareness and training in drinking water hygiene are necessary.

Abbreviations

CFU Colony Forming Unit

CV	Coefficient of Variation
NTU	Nephelometric Turbidity Unit
OR	Odds Ratio

Acknowledgments

The authors thank the technical staff of the Water and Food Laboratory of the National Institute of Public Hygiene for their contribution to collecting data and carrying out analyzes in the laboratory. They also thank the staff of the sanitation service at the regional INHP branch in Aboisso.

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Funding

This work is not supported by any external funding.

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Attaoui, Z. E., Sossi, F. Z. A., Khatori, Y. E. Management of risks threatening water quality: Application of the PROCESSES and the HACCP method. SHS Web of Conferences. 2023, 175. https://doi.org/10.1051/shsconf/202317501037

[2] Boko, G., Manou, B. E., Wertz, I., Drubbel, M. V., Kelome, N. A. Contribution of GIS in the diagnosis of the drinking water supply system in the town of Kétou in south Benin. Int J Biol Chem Sci. 2021, 15(3), 38–53. https://doi.org/10.4314/ijbcs.v15i1.29

[3] Bernard, N., Machado, A. Du droit à l'eau et de la précarité hydrique [The right to water and water poverty]. In Aménagement - environnement: urbanisme et droit foncier. 2021, 3, 145-166.

[4] WHO, UNICEF. Progress on sanitation and drinking water – 2015 update and MDG assessment. Geneve : World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF). 2015.

[5] Kouadio, L., Diarra, M., Akessé, D. P. V., Aboua K. N., Soro, B. D., Mérte, L., Dembélé, A., Koné, M., Traoré, S. K. Influence of the light source and the nature of water on the elimination of ciprofloxacin. J. Soc. Ouest-Afr. Chim. 2017, 044, 23–29.

[6] Beaulieu P, Fisset B. Tap water: A requirement of quality. Cah Nutr Diététique. 2009, 44(6), 294–301. https://doi.org/10.1016/j.cnd.2009.10.001

[7] Bontemps C., Nauges C. Carafe ou bouteille? Le rôle de la qualité de l'environnement dans la décision du consommateur. [Carafe or bottle? The role of environmental quality in consumer decisions]. Économie & Prévision. 2009, 188, 61–79. https://doi.org/10.3917/ecop.188.0061

[8] Reynaud, A., Garcia-Valiñas, M. A. Does Residential Water Use Depend on Water Quality? Some Answers from a French Case Study. In: Grafton Q, Daniell KA, Nauges C, Rinaudo J-D, Chan NWW, editors. Underst. Manag. Urban Water Transit., Dordrecht: Springer Netherlands. 20 15, p. 337–57. https://doi.org/10.1007/978-94-017-9801-3_16

[9] Ballet, T. G. N., Gnagne, A., Fofana, V., Yapo, B. O. Evaluation of households' perception about the quality of tap water in two communes, Cocody and Yopougon from Abidjan town, Côte d'Ivoire. Afr Sci. 2018, 14(6), 48–57.

[10] Koudou, A., Assoma, T. V., Niamké, K. H., Anoh, K. A., Adiaffi, B., Kouamé, K. F. Characterization and quantification of the relationship between hydrographic network and fracturing of the Agneby coastal watershed in Côte d'Ivoire. Afr Sci. 2018, 14(5), 311–324.

[11] Niamké G. M. Dégradation de l'environnement et santé de la population dans la ville d'Aboisso [Environmental degradation and population health in the town of Aboisso]. Thèse Unique de Doctorat. Université Félix Houphouët Boigny, Abidjan. 2016.

[12] Ake G. E., Eba A. E. L., Assi J. J., Kouadio B. H., Biemi J. GIS contribution to the delimitation of the protection perimeters around the water source of SODECI in Aboisso, South-East Côte d'Ivoire. Afr Sci. 2019, 15(3), 234–252.

[13] Konan, Y. A., Kessie, B. A., Kamelan, T. M., Kouamelan, E. P. Growth and reproduction parameters of *Brienomyrus brachyistius* (Gill, 1862) from the Lake Ayamé 1 (Bia river, Côte d'Ivoire). Agron Afr. 2021, 33(2), 215–229.

[14] Bain, R., Cronk, R., Hossain, R., Bonjour, S., Onda, K., Wright, J., Yang, H., Slaymaker, T., Hunter, P., Prüss-Ustün, A., Bartram, J. Global assessment of exposure to faecal contamination through drinking water based on a systematic review. Trop Med Int Health. 2014, 19(8), 917–927. https://doi.org/10.1111/tmi.12334

[15] Lavie, E., El-Tayib, N. H. From the tap to the mouth, drinking water quality in the domestic context in Khartoum, Sudan. Cybergeo Eur J Geogr, [En ligne], Espace, Société, Territoire, document 664. 2014. https://doi.org/10.4000/cybergeo.26157

[16] Amoukpo, H., Toffa, D., Boni, G., Salou Bachirou, Z., Wari, M., Fandohan, I., Aimade, H., Noudoffinin, N., Gouton, E., Fiossi, M., Agossadou, C., Mignanwande, F., Catraye, P., Bedie, V., Barogui, Y., Diez, G., Johnson, R. C. Improvement of the microbiological quality of drinking water in Lalo and Zè, two rural municipalities in Benin. Environ Risques Santé 2018, 17(6), 611–618. https://www.jle.com/10.1684/ers.2018.1240

[17] Coulibaly, M., Coulibaly, M., Diomandé, S. Analyse du mode d'accès, de conservation de l'eau et risques de maladies hydriques dans un quartier populaire: Cas de Kennedy Clouetcha dans la commune d'Abobo (Côte d'Ivoire). [Analysis of the mode of access, water conservation and risks of water-borne diseases in a working-class neighborhood: Case of Kennedy Clouetcha in the commune of Abobo (Ivory Coast)]. La revue des Sciences Sociales «Kafoudal». 2019, N°Spécial Janvier 2020, 122-141.

[18] Gbohaida, V., Agbangnan, D. C. P., Ngossanga, M. B., Medoatinsa, S. E., Dovonon, L. F. C., Wotto, D. V., Avlessi, F., Sohounhloue, D. C. K. Study of the physico-chemical quality of drinking water in two localities of Benin: Cotonou and Dassa-Zoumè. Int J Biol Chem Sci. 2016, 10(1), 422-434. https://doi.org/10.4314/ijbcs.v10i1.32

[19] Mvouezolo, R. F. L., Nkounkou, L. C., Foto, E., Ayessou, N., Mar, C. G., Ouamba, J. M. Hydrochemical quality and metallic contamination of the water distributed under pipeline in the city of Brazzaville, Congo. 2019, 15(1), 227–241.

[20] Daley, K., Truelstrup, H. L., Jamieson, R. C., Hayward, J. L., Piorkowski, G. S., Krkosek, W., Gagnon G. A., Castleden, H., MacNeil, K., Poltarowicz, J., Corriveau, E., Jackson, A., Lywood, J., Huang, Y. Chemical and microbial characteristics of municipal drinking water supply systems in the Canadian Arctic. Environ Sci Pollut Res. 2018, 25, 32926–32937. https://doi.org/10.1007/s11356-017-9423-5

[21] Rakotomaria, E., Ratsimba, M. H., Rakotomamonjy, P. Chemical promotion of the kaolin in water treatment: preparation of new coagulant minerals. Rev Sci L'eau. 2011, 24(4), 437–448. https://doi.org/10.7202/1007629ar

[22] Angui, K., Gone, D., Djebre, S. Comparative effects of unslaked lime and dolomite on some chemical parameters of a ferrasol and an organic soil in southern Côte d'Ivoire. Agron Afr. 2009, 21(2), 155-163. https://doi.org/10.4314/aga.v21i2.49805

[23] Dubovkina, I. Different methods of treatment of liquid systems and solutions: a review. Ukr J Food Sci. 2019, 7(2), 317–330. https://doi.org/10.24263/2310-1008-2019-7-2-14

[24] Odjegba, E., Amori, A., Zaccheaus, O., Awomeso, A., Adetula, B. Water Quality and Socio-economic Appraisal of Public Water Supply in Abeokuta, Southwest, Nigeria. 2015, 1(1-2), 193–203.

[25] Mbweb Katshil, P., Yav, N. N., Kashala, J. L. Comparative study on the quality of the water produced at REGIDESO factories in the center of Kolwezi with that distributed to customers: Case of the Mununka district in the commune of Manika, City of Kolwezi, DR Congo. Int J Innov Appl Stud. 2021, 35(1), 153–164.

[26] Dovonou, E. F., Hounsou, M. B., Sambienou, G. W., Adandedjan, C., Houessouga, F., Mama, D. Physico-chemical and bacteriological characterization of Rain water stored in tanks for consumption in the community of Toffo: case of the borough of Damè. J Appl Biosci. 2020, 154, 15871–15880.

[27] Wongpeerak, K., Charuwimolkul, N., Changklom, J., Lipiwattanakarn, S., Pornprommin, A. Theoretical Estimation of Disinfectant Mass Balance Components in Drinking Water Distribution Systems. Water. 2023, 15(2), 368. https://doi.org/10.3390/w15020368

[28] Mahfouz, A. S. B., El-Halwagi, M. M., Abdel-Wahab, A. Process integration techniques for optimizing seawater cooling systems and biocide discharge. Clean Technol Environ Policy. 2006, 8, 203–215. https://doi.org/10.1007/s10098-006-0046-7

[29] James, R. Dechlorination by ultraviolet radiation: a suitable alternative to activated carbon in dialysis water systems? J Ren Care. 2009, 35(4), 205–210. https://doi.org/10.1111/j.1755-6686.2009.00117.x

[30] Warren, A., Drogui, P., Laurion, I. A review of the current state of knowledge concerning the processes used for removal of cyanobacteria and cyanotoxins from drinking water. Rev Sci Eau. 2010, 23(4), 391–412. https://doi.org/10.7202/045100ar

[31] Yin, J., Gao, W., Yu, W., Guan, Y., Wang, Z., Jin, Q. A batch microfabrication of a self-cleaning, ultradurable electrochemical sensor employing a BDD film for the online monitoring of free chlorine in tap water. Microsyst Nanoeng. 2022, 8(1), 1-12. https://doi.org/10.1038/s41378-022-00359-1

[32] Dedić, S., Jukić, H., Rodić, M., Jusufhodžić, Z., Džaferović, A. Evaluation of Microbiological Parameters of Drinking Water from the Dobrenica Water Supply System in Ostrožac na Uni. In: Brka M, Omanović-Mikličanin E, Karić L, Falan V, Toroman A, editors. 30th Sci.-Experts Conf. Agric. Food Ind., Cham: Springer International Publishing; 2020, p. 281–287. https://doi.org/10.1007/978-3-030-40049-1_36

[33] Anayah, F., Al-Khatib, I. A., Hejaz, B. Assessment of water and sanitation systems at Palestinian healthcare facilities: pre- and post-COVID-19. Environ Monit Assess. 2021, 193, 41. https://doi.org/10.1007/s10661-020-08791-4

[34] Hounsounou, E. O., Tchibozo M. A. D., Ayi-Fanou, L., Agbossou, E. Public network's chain of water in some shantytowns of sixth district of Cotonou-Bénin. VertigO - Rev Électronique En Sci Environ. 2017, 17(3). https://doi.org/10.4000/vertigo.18824

[35] Ognard, C., Taglioni, F. Ressource en eau et fabrique du risque sanitaire au prisme de l'analyse de la vulnérabilité dans la capitale malgache [Water resources and the production of health risks through the prism of vulnerability analysis in the Malagasy capital]. Cah O-m. 2019, 280(2), 439–467. https://doi.org/10.4000/com.10528

[36] Ngnikam, E., Mougoue, B., Tietche, F. Eau, Assainissement et impact sur la santé: étude de cas d'un écosystème urbain à Yaoundé [Water, Sanitation and impact on health: case study of an urban ecosystem in Yaoundé]. Actes JSIRAUF, Hanoi: 2007, p. 13.

[37] Some, Y. S. C., Soro, T. D., Ouedraogo, S. Étude de la prévalence des maladies liées à l'eau et influences des facteurs environnementaux dans l'arrondissement de Nomgr-Masson: cas du quartier Tanghin (Ouagadougou-Burkina Faso) [Study of the prevalence of water-related diseases and influences of environmental factors in the district of Nomgr-Masson: case of the Tanghin district (Ouagadougou-Burkina Faso)]. Int J Biol Chem Sci. 2014, 8(1), 289–303. https://doi.org/10.4314/ijbcs.v8i1.25

[38] Tambekar W. S. Assessment of storage and handling practices on quality of household drinking water. BELS - Bull Enviromental Life Sci. 2022, 4(1), 12-17. https://doi.org/10.15167/2612-2960/BELS2022.4.1.2078