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Characterization of Well Water, Borehole Water and Wastewater in the Port Zone of Lomé: Physicochemical, Microbiological and Bioassay Approach

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Abstract

This study characterizes the physicochemical and microbiological quality of well water, borehole water, wastewater and water of the 4th lake in the port zone of Lomé. Fourteen (14) water samples were collected following usual sampling standards. Physicochemical analyses covered turbidity, conductivity, pH, nitrogen compounds, and trace metal elements, and biodegradability. Microbiological analyses targeted heterotrophic bacteria, thermotolerant coliforms, salmonella, and clostridia and performed according to the standardized methods of the French Association for Standardization. A bioassay using the larvae of *Artemia salina* was carried out in order to assess the toxicity of the samples. Physicochemical analyses revealed a high conductivity in almost all the samples tested (>400 µS/cm). Ammonium concentration was very high in one of the borehole waters 1 (12 mg NH_4^+/L). Nitrate concentration was high (>50 mg NO_3^-/L) in well water 1, 2, 4, and borehole water 1. Biodegradability index was high (>3) in wastewater 1, 2, 3 and 4. Trace metal elements like arsenic (As) showed very high concentrations, above 10 µg/L, in wastewater 4. Microbiological parameters, of various well water and borehole water samples contained heterotrophic bacteria and thermotolerant coliforms (TC) at very high values. Clostridium (Clost) were found in the surface water samples while salmonella (Sal) was found only in wastewater 2, 3 and 5. The mortality rate of the larvae of *Artemia salina* was mainly high in the wastewater samples. Water samples of the port zone of Lomé, whether they come from wells, boreholes or wastewater, show clear signs of contamination. Groundwater use for domestic, hygiene and food purposes should be subject to prior treatment in order to improve its quality and to reduce health risks and wastewater's heavy contamination underlines the urgent need for its appropriate management and treatment.

Keywords

Port, Wastewater, Boreholes, Wells, Pollution

1. Introduction

Water, a vital resource for all living beings, is a fundamental need of Man and is involved in domestic, hygiene and food use [1]. When it is taken as a drink, water must be potable. It must therefore meet the quality requirements set by the relevant standards concerning microbiological, chemical, radiological and aesthetic aspects [1]. Whether it is surface water (river, stream, lake or pond water) or groundwater (well, borehole, tap water), its quality is a determining factor for health [2]. Water quality is strongly influenced by anthropogenic pressures such as urbanization, industrialization, agriculture, port activities and shortcomings in sanitation. These human activities would therefore contribute to a deterioration of water quality through the production of pollutants that may end up in water [3]. Among these activities are those linked to ports and to mining. In Togo, previous work has highlighted the link between mining activities and cases of water pollution by heavy metals [4]. As regards port activities, they can lead to water pollution [5] through the accidental or deliberate discharge of hydrocarbons and waste by ships, and through run-off water which carries organic waste, heavy metals and particles towards water sources. In the port zone of Lomé, also classified as a free zone, the high concentration of industrial activities increases the risks of pollution. Indeed, this port free zone is heavily industrialized with nearly 36 industries, operating in the cosmetics, chemical, plastics, food, metal and pharmaceutical sectors [6]. These industries could also generate pollutants. In addition to these toxic substances, the presence of pathogenic microorganisms or bacteria can also alter water quality, thus contributing to water pollution [7]. Water pollution corresponds to its degradation or contamination through the introduction of toxic substances. These substances would affect the natural characteristics of water, in particular the biological and physicochemical characteristics, thus constituting a health risk in the event of consumption by the population. In 2019, water pollution was the cause of 1 - 4 million premature deaths throughout the world [8]. In Togo, previous studies carried out in certain localities of the country, in particular in Lomé [7], Tsévié [9], Tchaoudjo [10] and in the mining area of Bangéli [4] have made it possible to assess water quality in these areas. However, despite the high population density and the industrial concentration in the port zone of Lomé [8], no scientific data exist on the impact of port activities on the quality of the environment. This work therefore falls within the framework of the physicochemical and microbiological characterization of pollution in an industrial and urban setting with a view to assessing the water quality in the port zone of Lomé.

2. Material and Methods

2.1. Collection of the Water Samples

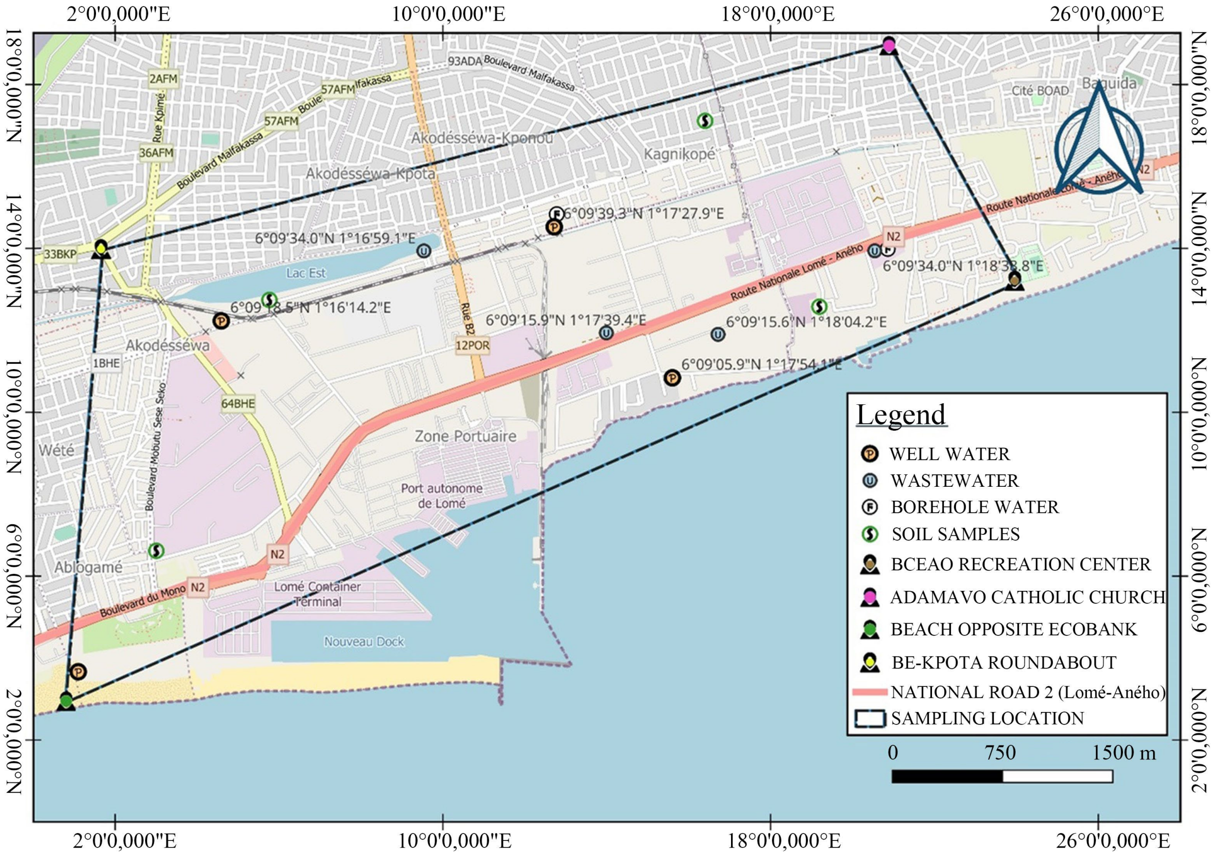

Figure 1. Map indicating the position of the sampling sites.

Fourteen (14) water samples were collected: four (04) from wells (W1-W4), five (05) from boreholes (BH1-BH5), four (04) from wastewater (WW1-WW4) and one (01) from the 4th lake (WW5). The sampling campaign was carried out in August 2025, corresponding to the short dry season in the south of Togo. The sampling points were geo-referenced using a Garmin 700 GPS. Figure 1 indicate the position of the sampling sites. The samples were collected according to the standard sampling and preservation standards within port zone of Lomé. This zone includes industrial activities area, business activities area and housing area.

The samples for the physicochemical analyses were collected in polyethylene bottles (1.5 L), while those intended for the microbiological analyses were taken in sterile borosilicate bottles [11].

After collection, the samples were kept in insulated cool boxes with cold accumulators, at a temperature of 5 ± 3˚C, in order to limit microbial activity and to preserve the integrity of the analyses [12]. The samples intended for the determination of cations and trace metal elements were acidified with nitric acid in order to prevent any precipitation.

2.2. Laboratory Analyses

The samples taken were subjected to physicochemical and microbiological analyses and to a bioassay.

2.2.1. Physicochemical Analyses

The physicochemical analyses covered the measurement of pH, turbidity, conductivity, temperature, nitrogen compounds (nitrates, nitrites, ammonium), phosphorus compounds (PO_4^{3-}), alkaline elements and trace metal elements (Hg, As, Pb, Cd, Zn, Ni, Cu).

For the wastewater and the water of the 4th lake, the chemical oxygen demand (COD) and the five-day biochemical oxygen demand (BOD_5) were determined. The COD and the BOD_5 made it possible to determine the degree of biodegradability of the wastewater. These analyses were conducted according to the analytical methods of the French Association for Standardization (AFNOR) as shown in **Table 1** [11].

Table 1. Materials and methods.

Physicochemical parameters		Equipment	Method	Standards
Temperature		Thermometer	Thermometer	Manufacturer's method
Alkalinity	Phenolphthalein alkalinity (TA)	Graduated burette	Titrimetry	ISO 9963-1/-2 1st ed 1994
	Total alkalinity (TAC)	Total alkalinity (TAC)	Graduated burette	Titrimetry
	CO_3	Graduated burette	Titrimetry	ISO 9963-1/-2 1st ed 1994
	HCO_3	Graduated burette	Titrimetry	ISO 9963-1/-2 1st ed 1994
Ph		WTW pH 330i pH meter	Electrometry	AFNOR NFT 90-008
Conductivity		WTW Cond 330i conductivity meter	Conductimetry	AFNOR 90-031
Nitrates		Digitron Elvi 675 spectrophotometer	Molecular absorption spectrometry	AFNOR NFT 90-012
Nitrites		Digitron Elvi 675 spectrophotometer	Molecular absorption spectrometry	AFNOR NFT 90-012
Ammonium		Digitron Elvi 675 spectrophotometer	Molecular absorption spectrophotometer	AFNOR NFT 90-015
Phosphates		Molecular absorption spectrophotometer	Spectrometry	ISO 6878/2nd ed 2004
Sulfates		Digitron Elvi 675 spectrophotometer	Nephelometry	AFNOR NFT 90-009
COD		Reflux digestion block	Acidimetry	ISO 6060
BOD_5		Incubation bottles Glassware	Dilution method	ISO 5815-1 & 2:

Continued

Trace metal elements (cadmium, lead, zinc)		Flame atomic absorption spectrometer	Atomic absorption spectrophotometry	
Trace metal elements (arsenic)		Atomic absorption spectrometer + Hydride Generation module	Atomic absorption spectrophotometry	
Trace metal elements (mercury)		Atomic absorption spectrometer + Cold vapor module	Atomic absorption spectrophotometry	
Hardness	Total hardness (TH)	Graduated burette	Complexometry	T 90-003 AFNOR-R-9th ed
	Mg	Graduated burette	EDTA complexometry	AFNOR NFT 90-016
	Ca	Graduated burette	EDTA complexometry	AFNOR NFT 90-016
Salinity	Na	Perkin Elmer model 2380 spectrophotometer	Atomic absorption spectrophotometer	AFNOR NFT 90-20
	Cl	Graduated burette	Argentometry	AFNOR NFT 90-014
K		Perkin Elmer model 2380 spectrophotometer	Atomic absorption spectrophotometer	AFNOR NFT 90-20
F			Spectrophotometry (colorimetry)	Water analysis methods according to Rodier
$KMnO_4$		Graduated burette	Hot acid method	ISO 8467/2nd ed 1993
Organoleptic	Odour		Olfactory	ISO 8586
	Colour	Molecular absorption spectrophotometer	Cobalt-platinum	Manufacturer's method.

ISO: International Organization for Standardization, BOD_5: Five-day biochemical oxygen demand, COD: Chemical oxygen demand, AFNOR: French Association for Standardization.

2.2.2. Microbiological Analyses

These analyses were carried out in accordance with the recommendations in force for the microbiological analyses of food and water samples as shown in Table 2 [12].

Table 2. Equipment and standards used for the microbiological analyses.

Target microorganisms	Equipment/culture media	Standards
Total aerobic mesophilic flora (TAMF) and heterotrophic microorganisms	Plate count agar for water (PCA)	EN ISO6222
Thermotolerant coliforms	Chromogenic coliform agar (CCA)	EN ISO 9308-1
Faecal enterococci or faecal streptococci in drinking water	Slanetz-Bartley agar and bile esculin agar	EN-ISO 7899-2
Clostridium	Tryptose sulfite cycloserine agar (TSC)	EN 26461-2
Salmonella	XLD (xylose lysine deoxycholate) agar and Hektoen agar	ISO 6579
Faecal enterococci in wastewater	Rothe broth	EN ISO 7899-1
Coliforms in wastewater *E. coli in wastewater*	2% brilliant green bile lactose broth	

E. coli: Escherichia coli; ISO: International Organization for Standardization.

2.2.3. Bioassay

In the framework of this study, the larvae of *Artemia salina* (crustacean) were used as biological material to assess the toxicity of the water samples of the port zone according to the methods of Lu *et al.* [13] and of Dossou-Yovo *et al.* [14], slightly modified. For each sample and control, 6 replicate were done and the average number of dead larvae was determined and the mortality rate calculated by applying Abbott's correction formula (% Toxicity = [(treated mortality - control mortality)/(100 -control mortality)] × 100).

The test was validated only if the mortality rate of the larvae did not exceed 10% in the control batches.

3. Results

The results were presented by type of water (well water, borehole water and wastewater) and by group of parameters (physicochemical and microbiological parameters), as well as the bioassays.

3.1. Physicochemical Parameters

Tables 3-5 present the main physicochemical parameters as well as the organoleptic characteristics of the groundwater (wells and boreholes) and of the surface water (wastewater and 4th lake). Parameters such as taste, odour, pH, turbidity and temperature were normal in the groundwater samples. In contrast, conductivity exceeded the values recommended by the European Union guidelines. Likewise, the ammonium concentration was particularly high in sample BH1.

Concerning the surface water, only one sample out of five was odourless. Some showed a high turbidity (WW3 and WW4). The conductivity of these surface water samples was also high (WW1 and WW4).

Furthermore, some samples showed high contents of alkaline elements such as Na, K, Fe and Cl (W1, W2 and BH1).

Table 3. Physicochemical parameters of well water.

Parameters analysed	Well water				Permissible conc (RF* UE**)	WHO guidelines
	W1	W2	W3	W4		
Odour	Odourless	Odourless	Odourless	Odourless	None	-
Taste	Tasteless	Tasteless	Tasteless	Tasteless	None	-
Turbidity-NTU	0.1	0.87	0.18	0.14	-	<5
Temperature (˚C)	27.4	27.4	27.4	27.4	<25	-
pH	7.05	7.01	7.12	7.39	6.5 - 8.5 (*)	6.5 - 9.5
Conductivity at 25˚C µs/cm	1598	1693	656	1039	400 (**)	
TA (mg/L of $CaCO_3$)	0	0	0	0	-	-
TAC (mg/L of $CaCO_3$)	225	275	140	240	-	-
CO_3 (mg/L)	0	0	0	0		
HCO_3 (mg/L)	274.5	335.5	170.8	292.8		

Continued

TH (mg/L of $CaCO_3$)	400	330	158	272	150 - 500 (*)	
Ca (mg/L)	140	96	55.2	76		
Mg (mg/L)	12	21.6	4.8	19.68		
Na (mg/L)	170	224	80	126	≤150 (*)	≤200
K (mg/L)	32.3	9.4	12.6	17.8	≤12 (*)	-
Fe (mg/L)	<0.05	1.76	<0.05	<0.05	≤0.2 (*)	≤0.3
Mn (mg/L)	<0.05	<0.05	<0.05	<0.05	≤0.05 (*)	0.4
Cl (mg/L)	200	210.23	66.1	130.1	≤200 (*)	≤250
SO_4 (mg/L)	120.88	180	47.37	74.56	≤250 (*)	≤400
PO_4 (mgP/L)	<0.2	<0.2	<0.2	<0.2	≤5 (*)	-
F (mg/L)	<1	1.25	<1	<1		1.5
$KMnO_4$ (mgO_2/L)	2	3	1.1	0.6	<5	-
NH_4^+ (mg/L)	<0.1	<0.1	<0.1	<0.1		≤1.5

W: Well water, (*) French Regulations (RF), (**) European Union (EU) Directive.

Table 4. Physicochemical parameters of borehole water.

Parameters analysed	Borehole water						
	BH1	BH2	BH3	BH4	BH5	Permissible conc (RF* UE**)	WHO GUIDELINES
Odour	Odourless	Odourless	Odourless	Odourless	Odourless	None	-
Taste	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	None	-
Turbidity-NTU	0.22	0.27	0.33	0.24	0.11	-	<5
Temperature (˚C)	25.3	25.5	25.3	25.2	25.7	<25	-
pH	7.01	7.64	7.49	6.92	7.36	6.5 - 8.5 (*)	6.5 - 9.5
Conductivity at 25˚C µS/cm	1448	1231	1098	356	1123	400 (**)	
TA (mg/L of $CaCO_3$)	0	0	0	0	0	-	-
TAC (mg/L of $CaCO_3$)	265	270	250	85	125	-	-
CO_3 (mg/L)	0	0	0	0	0		
HCO_3 (mg/L)	323.3	329.4	305	103.7	152.5		
TH (mg/L of $CaCO_3$)	340	150	160	95	146	150 - 500 (*)	
Ca (mg/L)	100	32	36	26.8	28		
Mg (mg/L)	21.6	16.8	16.8	6.72	18.2		
Na (mg/L)	204	192	156	28.8	160	≤150 (*)	≤200
K (mg/L)	7.3	25.3	25.6	12.6	24.4	≤12 (*)	-
Fe (mg/L)	0.25	0.06	0.12	0.48	<0.05	≤0.2 (*)	≤0.3
Mn (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	≤0.05 (*)	0.40
Cl (mg/L)	160.17	210.26	200.23	20	239.23	≤200 (*)	≤250
SO_4 (mg/L)	170	12.2	10	32.63	29.8	≤250 (*)	≤400

Continued

PO_4 (mgP/L)	0.44	<0.2	<0.2	<0.2	<0.2	≤5 (*)	-
F (mg/L)	1.01	1.49	1.57	<1	1.82		1.5
$KMnO_4$ (mgO_2/L)	1.7	0.1	0.1	0.6	0.4	<5	-
NH_4^+ (mg/L)	12	<0.1	3.4	0.27	<0.1		≤1.5

BH: Borehole water, (*) French Regulations (RF), (**) European Union (EU) Directive.

Table 5. Physicochemical parameters of wastewater.

Parameters analysed	Wastewater and water of the 4th lake					
	WW1	WW2	WW3	WW4	WW5 (4th Lake)	Interministerial order: MER/MS/MERF No. 010 of 30 March 2015
Odour	Odourless	Yes	Yes	Yes	Yes	
Taste	Salty	-	-	-	-	
Turbidity-NTU	1.15	1.63	101.25	43.7	1.47	
Colour	<5	>100	>100	>100	15	
Temperature (˚C)	25.2	25.5	25.7	25.4	27.5	
pH	7.74	5.08	7.48	4.35	7.99	5.5 - 9
Conductivity at 25˚C µS/cm	2660	2360	2010	8590	1457	≤2500
TA (mg/L of $CaCO_3$)	0	0	0	0	0	
TAC (mg/L of $CaCO_3$)	330	40	310	0	255	
CO_3 (mg/L)	0	0	0	0	0	
HCO_3 (mg/L)	402	48.8	378.2	0	311.1	
TH (mg/L of $CaCO_3$)	220	180	230	200	204	
Ca (mg/L)	40.4	45	48	40.1	48	
Mg (mg/L)	28.4	21.0	26.4	21.15	20.16	
Na (mg/L)	377	375	302	3560	228	
K (mg/L)	58.5	8	51	10	22.6	
Fe (mg/L)	0	<0.05	37.6	18.46	<0.05	
Mn (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	≤1
Cl (mg/L)	540.59	560.62	260.28	700.77	270.3	≤1200
SO_4 (mg/L)	20.18	249.1	245.6	245.6	48.3	
PO_4 (mgP/L)	0.25	2.5	4.25	0.63	0.6	
F (mg/L)	1.88	7.84	<1	2.57	<1	≤15
$KMnO_4$ (mgO_2/L)	0.5	70	280	180	2.8	

WW: Wastewater.

3.2. Nitrate, Nitrite and Phosphorus Concentrations

The results recorded in Table 6 and Table 7 indicate that in some groundwater samples (W1, W2, W4 and BH1) the nitrate concentration was high compared with the WHO guidelines. The nitrite concentrations were also above the standards in some samples (W1 and BH1).

Concerning phosphorus, high contents were observed in some groundwater samples (W2 and BH1), compared with the WHO guidelines.

Table 6. Nitrate and nitrite concentrations in well water.

Parameters analysed	Well water				Permissible conc (RF* UE**)	WHO guidelines (mg/L)
	W1	W2	W3	W4		
NO_3^- (mg NO_3^-/L)	63	81.3	26.2	144.25	≤50 (*)	≤50
NO_2^- (mg NO_2^-/L)	3.7	0.6	0.18	0.10	≤0.1 (*)	≤3
P (mg/L)	0.49	1.06	0.09	0.06	-	1

W: Well water.

Table 7. Nitrate and nitrite concentrations in borehole water.

Parameters analysed	Borehole water						
	BH1	BH2	BH3	BH4	BH5	Permissible conc (RF* UE**)	WHO guidelines (mg/L)
NO_3^- (mg NO_3^-/L)	103.75	<0.5	<0.5	24.5	8.86	≤50 (*)	**≤50**
NO_2^- (mg NO_2^-/L)	3.24	<0.02	<0.025	0.04	<0.02	≤0.1 (*)	**≤3**
P (mg/L)	1.04	<0.05	<0.05	<0.05	<0.05	-	1

BH: Borehole water.

3.3. Determination of Suspended Solids (SS), Five-Day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD) and Nitrate Concentration (NO_3^-) in Wastewater

Table 8. SS, BOD_5, COD, P and NO_3^- in wastewater.

Parameters analysed	Wastewater					
	WW1	WW2	WW3	WW4	WW5	Interministerial order: MER/MS/MERF No. 010 of 30 March 2015
SS (mg/L)	17.33	266.7	871.25	734.82	22.44	≤50
BOD_5 (mg O_2/L)	8	235.0	68	3410	30	≤100
COD (mg O_2/L)	67.2	1400	340.8	16,448	48	≤300
COD/BOD_5	8.4	5.96	5	4.82	1.6	
NO_3^- (mg NO_3^-/L)	<0.5	<1.4	86	<0.5	<0.5	≤20
P (mg/L)	<0.29	<0.05	7.3	0.1	0.42	≤10

WW: Wastewater.

Table 8 summarizes the results of the COD and of the BOD_5 for the surface water sampless (wastewater and water of the 4th lake) as well as their nitrate concentration and the degree of biodegradability. SS and COD were high in three of the 5 samples (WW2, WW3 and WW4). BOD_5 showed significant values in WW2 and WW4, while the nitrate concentration was high in WW3. The degree of biodegradability was above the thresholds in WW1, WW2, WW3 and WW4.

3.4. Trace Metal Elements

Table 9 and Table 10 summarize the values of certain trace metal elements, namely Cadmium (Cd), Lead (Pb), Mercury (Hg) and Arsenic (As), in the groundwater (well water, borehole water).

Table 9. Content of trace metal elements (Cd, Pb, As and Hg) in well water.

Parameters analysed	Well water				
	W1	W2	W3	W4	WHO guidelines in 2006 (µg/L)
Cd (µg/L)	<2.8	<2.8	<2.8	<2.8	3
Pb (µg/L)	<10	<10	<10	<10	10
As (µg/L)	<0.05	<0.05	<0.05	<0.05	10
Hg (µg/L)	<0.15	<0.15	<0.15	<0.15	6

W: Well water.

Table 10. Content of trace metal elements (Cd, Pb, As and Hg) in borehole water.

Parameters analysed	Borehole water					
	BH1	BH2	BH3	BH4	BH5	WHO guidelines 2006 (µg/L)
Cd (µg/L)	<2.8	<2.8	<2.8	<2.8	<2.8	3
Pb (µg/L)	<10	<10	<10	<10	<10	10
As (µg/L)	<0.15	<0.15	<0.15	<0.15	<0.15	10
Hg (µg/L)	<0.15	<0.15	<0.15	<0.15	<0.15	6

BH: Borehole water.

Table 11. Heavy metal content (Cd, Pb, As and Hg) of wastewater.

Parameters analysed	Wastewater					
	WW1	WW2	WW3	WW4	WW5 (4th Lake)	Interministerial order: MER/MS/MERF No. 010 of 30 March 2015 (µg/L)
Cd (µg/L)	<2.8	<2.8	<2.8	<2.8	<2.8	≤200
Pb (µg/L)	<10	<10	<10	<10	<10	≤500
As (µg/L)	<0.05	<0.05	<0.05	65	<0.05	≤10
Hg (µg/L)	<0.15	<0.15	0.15	15.0	<0.15	≤50

WW: Wastewater.

Table 11, for its part, indicates the content of trace metal elements in the surface water (wastewater and water of the 4th lake). For sample WW4, the As and Hg contents were detected at particularly high concentrations. Likewise, sample

WW3 showed a high Hg concentration.

Tables 12-14 record the values of the content of trace metal elements such as Zn, Cu and Ni detected in the various samples of well water, borehole water, wastewater and water of the 4th lake.

In the groundwater (well water, borehole water), the contents found are below the detection threshold. In wastewater, Zn content is high in the sample 3 (WW3).

Table 12. Content of trace metal elements in well water.

Parameters analysed	Well water				
	W1	W2	W3	W4	WHO guidelines in 2006 (mg/L)
Zn (mg/L)	<0.0033	<0.0033	<0.0033	<0.0033	3
Cu (mg/L)	<0.004	<0.004	<0.004	<0.004	2.0
Ni (mg/L)	<0.0054	<0.0054	<0.0054	<0.0054	0.07

W: Well water.

Table 13. Content of trace metal elements in borehole water.

Parameters analysed	Borehole water					
	BH1	BH2	BH3	BH4	BH5	WHO guidelines (mg/L) 2006
Zn (mg/L)	<0.0033	<0.0033	<0.035	<0.0033	<0.0033	3
Cu (mg/L)	<0.004	<0.004	<0.004	<0/004	<0.004	2
Ni (mg/L)	<0.0054	<0.0054	<0.0054	<0.0054	<0.0054	0.07

BH: Borehole water.

Table 14. Content of trace metal elements in wastewater.

Parameters analysed	Wastewater and 4th Lake					
	WW1	WW2	WW3	WW4	WW5 (4th Lake)	Interministerial order: MER/MS/MERF No. 010 of 30 March 2015
Zn (mg/L)	<0.0033	0.0033	3.20	1.45	<0.035	≤2
Cu (mg/L)	<0.004	<0.004	<0.25	<0.004	<0.004	≤0.5
Ni (mg/L)	<0.0054	<0.0054	<0.07	<0.12	<0.0054	≤0.5

WW: Wastewater.

3.5. Microbiological Data

Table 15 and Table 16 present the microbiological parameters of the groundwater (well water and borehole water). Heterotrophic Plate Count (HPC) and thermotolerant coliforms (TC) were detected in the well water and borehole water samples. The well samples showed high loads HPC bacteria and TC. The borehole samples also showed high values in the majority of cases.

Table 17, for its part, presents the results of the microbiological parameters in the surface water (wastewater and water of the 4th lake). Samples WW2, WW3, WW4 and WW5 showed high TC concentrations. Likewise, the enterococci

(ENT) concentration was high for samples WW2, WW3 and WW4. Clostridium (Clost) were detected in the surface water samples. In contrast, salmonella (Salm) was detected only in WW2, WW3 and WW5.

Table 15. Essential microbiological parameters of well water.

Parameters analysed	Well water				WHO guidelines (CFU/mL) 2006
	W1	W2	W3	W4	
HPC at 37˚ CFU/mL	>3000	>2600	>3000	>3000	≤10
TC CFU/100 mL	>1500	>1500	>1500	>1500	<1

W: Well water, **HPC**: Heterotrophic Plate Count, **TC**: Thermotolerant coliforms.

Table 16. Essential microbiological parameters of borehole water.

Parameters analysed	Borehole water					
	BH1	BH2	BH3	BH4	BH5	WHO guidelines (CFU/mL) 2006
HPC at 37˚ CFU/mL	68	20	5900	830	150	≤10
TC CFU/100 mL	30	<1	1600	90	180	<1

BH: Borehole water HPC: Heterotrophic Plate Count, TC: Thermotolerant coliforms.

Table 17. Essential microbiological parameters of surface water (wastewater and water of the 4th lake).

PARAMETERS ANALYSED	Wastewater					
	WW1	WW2	WW3	WW4	WW5 (4th Lake)	Interministerial order: MER/MS/MERF No. 010 of 30 March 2015
TC CFU/100 mL	70	>9000	>15,000	>15,000	3500	≤2000
ENT MPN/100 mL	<0.5	230,000	5,600,000	56,000	43	≤1000
Clost CFU/100 mL	210	700	15,000	18	1000	
SALM in 100 mL	Not detected	Detected	Detected	Not detected	Detected	

WW: Wastewater, **CT**: Thermotolerant coliforms at 44˚C; **ENT**: Enterococci; **Clost**: Clostridium, **SALM**: Salmonella spp.

3.6. Bioassay Data

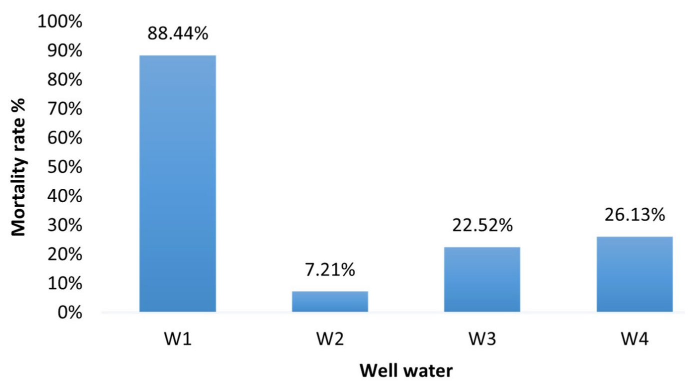

Figure 2. Mortality rate of the larvae of *Artemia salina* in well water.

Figures 2-4 represent the mortality rates of the larvae of *Artemia salina* in the various water samples. The mortality rate was high in W1, W2, W3, W4 and W5.

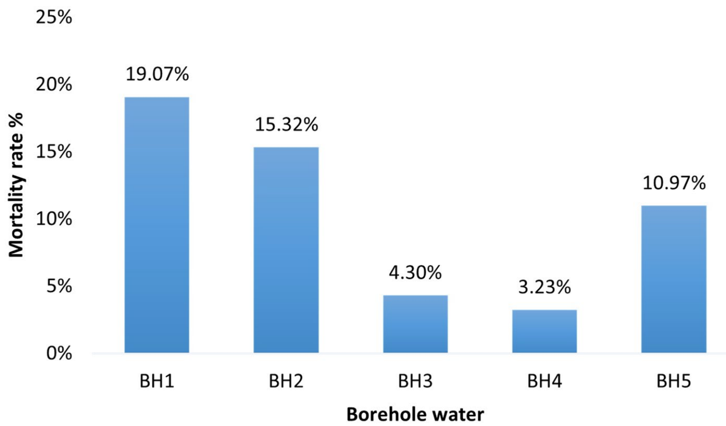

Figure 3. Mortality rate of the larvae of *Artemia salina* in borehole water.

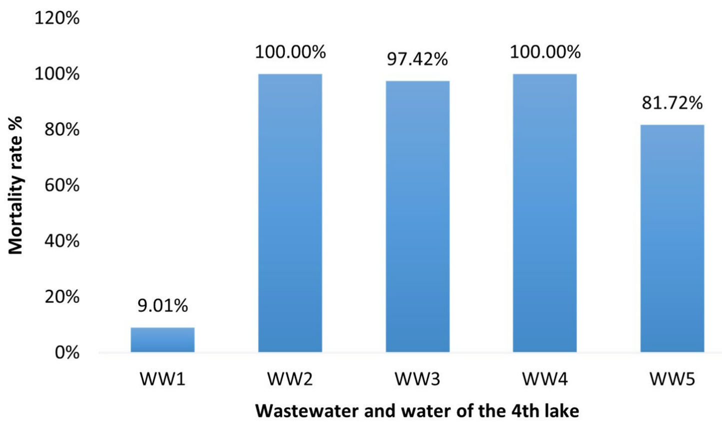

Figure 4. Mortality rate of the larvae of *Artemia salina* in wastewater and of the 4th lake.

4. Discussion

Water quality is influenced by various factors, in particular anthropogenic activities [14], and can be assessed through physicochemical and microbiological parameters. Among these parameters, mention may be made of physicochemical parameters such as turbidity, temperature, conductivity, pH, the concentration of mineral elements (ammonium ion, calcium, magnesium, chloride, sodium, nitrates) [10] or organoleptic characteristics such as taste and odour [1].

Turbidity is a parameter that makes it possible to measure the cloudiness of water. It is due to suspended particles such as sediments, organic matter and microorganisms [15]. A high turbidity reflects potential pollution, the suspended particles being able to constitute vectors of heavy metals and microorganisms. The results of this study on the groundwater samples (well water, borehole water) made it possible to record a turbidity below the limits recommended by the WHO (≤5 NTU) [15]. This result is similar to that of Ouéda *et al.* [10] who detected a turbidity complying with the WHO standards in the water samples of the

Didaourè agglomeration (Tchaoudjo 1). In contrast, our results differ from those of Tampo *et al.* [16], who recorded a turbidity above the standard in well water during their work in Démakpoé and Agbalépédogan (Lomé) [16]. In contrast, in the surface water (wastewater 3 and 4), turbidity was high, indicating possible pollution of these waters. The high turbidity observed in these samples would therefore be linked to the presence of insoluble solid particles in suspension. This result as regards wastewater is similar to those of Ayah *et al.* [3] who recorded a high turbidity (35 NTU) during a study on the lagoon system of Lomé [3].

The SS values of these two samples were also high, far exceeding the regulatory value set by interministerial order MER/MS/MERF No. 010 of 30 March 2015 (≤50 mg/L) [17]. This result is also similar to those of Ayah *et al.* [3] who indicated an SS of 77 mg/L in the lagoon system of Lomé [3].

According to the WHO, water temperature should not exceed 25˚C. In this study, some well waters and one wastewater sample exceeded this limit, which could favour microbial proliferation. Indeed, a high water temperature would favour the proliferation of bacteria [18]. This result is similar to those of Ouéda *et al.* [10] who, during their work in the Tchaoudjo 1 area, recorded an average water temperature of 26.17˚C, therefore above the WHO standard. Likewise, the work of Fambi *et al.* [19] in Togo, like that of Dégbey *et al.* [20] in Benin, also recorded temperatures above the WHO standards.

As regards pH, a physicochemical parameter which provides information on the acidity or the basicity of an aqueous solution, drinking water, according to the WHO, has an optimum pH between 6.5 - 9.5 [21] [22]. The various well water and borehole water samples had a pH complying with the WHO standards. Our results are similar to those of Ouéda *et al.* [10] who during their work recorded pH values complying with the WHO standards. However, our results differ from those of Fambi *et al.* [19] who noted, during a study in 2021 on the borehole water of Légbassito and Vakpossito, two localities in the south of Togo, that 70 % of the waters had an acidic pH. These pH values were between 4.94 and 5.9 [19]. As regards wastewater, one sample had a pH not complying with the standard defined by interministerial order MER/MS/MERF No. 010 of 30 March 2015. Indeed, according to this order, the pH of wastewater should lie between 5.5 - 9 [17]. Wastewater sample 4 (WW4), which shows an acidic pH (4.35), and wastewater sample 2 (WW2) do not comply with the national regulations on wastewater. Thus, apart from wastewater sample 4 and, to a lesser extent, wastewater sample 2, the results of our study are similar to those obtained in Morocco by Boutayeb *et al.* [23], who recorded pH values between 7.05 and 8.2 for various wastewater samples.

Conductivity, which reflects the mineralization of water, expresses its capacity to carry the electric current. It was high both in the groundwater (well and borehole water) and in the surface water (wastewater and water of the 4th lake). This result is different from that of Gnazou *et al.* [24] who obtained a conductivity ranging from 70.5 µS/cm to 1756 µS/cm. In contrast, our result is similar to that of Talhaoui *et al.* [25] who recorded conductivities, with a maximum of 2240 µS/cm during their work in Morocco. According to the European Union (EU) standards, conductivity should be less than or equal to 2500 µS/cm, but permissible value is 400 µS/cm for drinking water. A high conductivity would indicate natural pollution (erosion of rocks) or anthropogenic pollution (agriculture, industries or domestic discharges) [15].

Our study also revealed, in some well water samples (W1, W2 and W4), borehole water samples (BH1) and wastewater samples (WW3), the presence of nitrogen compounds such as nitrates at concentrations above the EU and WHO standards. As regards well water, our results are similar to those of Gnazou *et al.* [24] who had also recorded high nitrate concentrations in well water in the Zio area. Likewise, the work of Ouéda *et al.* [10], indicated that 66.67% of the water samples studied in the Didaourè agglomeration had a nitrate concentration above the WHO standards. Ahoudi *et al.* [22] during their work in the Agoè Zongo area, also recorded high nitrate contents in the various water samples. High nitrate concentrations reflect contamination linked to the leaching of agricultural soils or to urban and industrial discharges.

The ammonium ion, another nitrogen compound, was present at a high concentration in borehole sample 1 (BH1). This result associated to nitrite and nitrate high level in BHI, indicate a possible punctual source of contamination, mainly a possible domestic contamination (human discharges) [10]. This result is similar to that of Ouéda *et al.* [10], who recorded a high level of ammonium ion in one of their water samples.

The COD of some wastewater samples (WW2, WW4) was high compared with the standard set by interministerial order MER/MS/MERF No. 010 of 30 March 2015 [17]. These results reveal a heavy contamination by refractory pollutants of organic and mineral origin [23]. Indeed, the chemical oxygen demand provides information on possible organic pollution of water [26]. Our results are similar to those of Sema *et al.* [27] who, during their work in Kara, also recorded high COD values. However, these COD values were high only in the mornings, owing to the discharge of wastewater by the industries [27].

As for the biochemical oxygen demand over 5 days (BOD_5), its value in the wastewater samples (WW2 and WW4) did not comply with the standards in force in Togo. Moreover, the biodegradability index of the wastewater (WW1-WW4) was above 3, thus confirming the presence of non-biodegradable refractory pollutants [28]. Indeed, the biodegradability index makes it possible to assess the biodegradability of organic matter [28] while giving indications on the origin of the pollution [29].

Finally, as regards the concentrations of trace metal elements, the contents found in well water and borehole water were generally in compliance with the WHO Guidelines in 2006. In contrast, in some wastewater samples, the content of trace metal elements such as As did not comply with the Togolese regulations in this field. These results are similar to those of Kpiagou *et al.* [30] who had also detected high levels of As in the water resources of the Didagou catchment. These results underline the need for an appropriate treatment of wastewater. Indeed, trace metal elements are non-biodegradable toxic pollutants which accumulate in the environment with negative impacts on health [31].

Most of the wastewater also had an odour, testifying to the alteration of the organoleptic characteristics.

Biological assessment, in particular microbiological analysis, constitutes another component of the study of water quality.

In the groundwater and surface water samples, the presence of heterotrophic bacteria at values clearly above the WHO guidelines would indicate a contamination of the water following exposure to overall pollution.

Thermotolerant coliforms (TC) were also found in the groundwater samples at abnormal values, indicating suspected faecal contamination [7]. The heterotrophic plate count and TC values in well water are clearly higher than those found in borehole water (except those of BH2). This difference would be linked to the fact that boreholes are generally deeper and less exposed than wells [11]. The results obtained in this study as regards HPC bacteria and TC in well water and borehole water are similar to those of previous work carried out in Adakpamé [11] and Lomé [7]. This work indeed also recorded the presence of HPC bacteria and faecal coliforms in well water and borehole water. As regards wastewater, only one sample showed TC and enterococci values below the national standards.

Salmonella and clostridia were also found in most of the wastewater. These pathogenic bacteria are indeed often found in wastewater [32].

Just like the physicochemical and microbiological analyses, bioassays also make it possible to assess water pollution [13]. The bioassay with the larvae of *Artemia salina* indeed makes it possible to obtain indications on possible toxicity and on the ecological quality of the water. The high mortality rates observed in the majority of the wastewater and in one well sample can reveal probable toxicity.

The larvae of *A salina* therefore made it possible to obtain indications on the toxicity of the various water samples of the port zone, by serving as bioassay material.

5. Conclusion

The physicochemical analysis highlighted several anomalies, particularly in the wastewater. From the microbiological point of view, the well water, borehole water and wastewater were contaminated by heterotrophic bacteria and by pathogenic germs. To this is added the high mortality observed during the bioassay on the larvae of *Artemia salina*, particularly in the wastewater. These results reflect a probable pollution of the waters in the port zone of Lomé. Further researches must be conducted to determine rather contaminations are due to Lomé's port activities or not.

Conflicts of Interest

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

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