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Physico-chemical characteristics of drinking water in the city of Daloa (Côte d'Ivoire)

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Abstract
This study aims to assess the physico-chemical and mineral composition of water consumed in Daloa. The samples taken from ten sites made it possible to determine the biochemical composition of these waters. Using standard and referenced methods, the chemical physical parameters and the mineral composition of these waters were evaluated. They are generally acidic with pH values ranging from 3.98 to 6.30. These waters are weakly mineralized except for the samples from GARAGE (451.33 µS/cm) and ORLY 1 (681 µS/cm) districts, which have values above the standard prescribed by WHO (< 400 µS/cm). In addition, the different types of water in Daloa are generally cloudy except for water from the EVECHE spring, which has a turbidity of 0.17 NTU below the standard for drinking water. These Daloa waters contain minerals that have concentrations that meet the standards prescribed by the WHO for drinking water. These are calcium, potassium, sodium, nitrates, chloride, sulphide, bicarbonates, iron, copper, chromium, zinc, lead. On the other hand, the concentrations of arsenic and cadmium in the waters of TAZIBOUO, ORLY 1 & 2, GARAGE, EVECHE and the Pastoral Institute are high. Also the Water Distributed by the Company of Côte d'Ivoire called in french¨Société de Distribution d'Eau de Côte d'Ivoire˝(SODECI) contains a significant amount of cadmium and aluminum. The consumption of this water can therefore be dangerous for the health of consumers if no action is taken by the hygiene service of the municipality of Daloa.

Keywords: Water type, water quality, biochemical composition, Daloa (Côte d'Ivoire)

Introduction
Drinking water is water intended for human consumption and which is not likely to harm health in its everyday use. WHO (2017) [1] guidelines indicate that water security and quality are fundamental for human development and well-being. However, water can also be a source of disease due to its contamination by household, industrial, agricultural and organic waste. It is for this reason that the quality of drinking water appears to be a worrying issue all over the world (Blé & Mahaman, 2009) [2]. The work of WHO/UNICEF (2017) [21] has shown that 30% of the world's population does not have access to domestic drinking water supply services.
Particularly, in developing countries where the infrastructure of basic services does not keep up with population growth due to anarchic urbanization leads to difficulties in supplying drinking water for the populations. In Côte d'Ivoire, as in most African countries, people are faced with this difficulty. In particular, in the city of Daloa, a large proportion of households are not connected to the Water Distribution Company of Côte d'Ivoire (SODECI) according to survey data from Diarra *et al.* (2016) [4] and Kossonou *et al.* (2022) [5]. Most people use water from natural springs, fountains and wells as drinking water. According to Frantzy (2017) [6], waterborne diseases are caused by the consumption of unsanitary water. These waterborne diseases are generally related to biological agents or physico-chemical parameters. Water is an essential element for the life of humans, animals and plants. It seemed important to us to measure the physico-chemical parameters and the minerals contained in these different consonant water sources in this third largest city of Côte d'Ivoire. Indeed, for water to be intended for drinking, it must me*et al*l the quality guidelines set by the WHO. It exceeds a certain interval of physico-chemical parameter and promotes a complete absence of faecal germs indicators of contamination. Sanitation and access to drinking water are therefore essential elements for improving living conditions and human health (Wari, 2012) [7]. According to the United Nations (UN), 36,000 peoples around the world die daily from lack of drinking water and lack of sanitation (WHO, 2010) [8]. Unsafe water alone causes approximately four million child deaths per year from diarrhea (WHO/UNICEF, 2009) [9]. This

is why this study proposes to evaluate the physico-chemical and mineral characteristics of the water consumed in Daloa in order to be located on the sanitary state of the waters used in this city.

Materials and Methods

Material studied

The drinking water distributed in the streets of Daloa was used for the various physico-chemical and mineral analyses. This is water from natural springs, wells, fountains and the circuit distributed by the˝ Société de Distribution d'Eau de Côte d'Ivoire˝ (SODECI). Table 1 presents the different drinking water samples used for this study.

Equipment and apparatus used for physico-chemical analysis

The use of a pH meter, a conductivity meter, a turbidimeter and a spectrophotometer (ICP AVIO 200) were necessary for the respective determinations of pH, conductivity, turbidity and mineral concentration.

Methods

Sampling

Based on the work carried out by Kossonou *et al*. (2022) [5], we carried out sampling by taking several different water sources. The water samples were labeled according to their source, the day, the place and the sampling number. In the commune of Daloa, there are mainly four types of water commonly used. This is water distributed by the˝ Water Distribution Company of Côte d'Ivoire˝ (SODECI), well water, natural spring water and fountain water.

These ten water samples were sent to the Biotitiale physical chemistry laboratory in a cooler for the various analyses.

Physico-chemical analysis

pH

The pH was measured with a digital pH meter (Mettler Toledo, China) according to the method described by ISO 10523. A quantity of 50 mL of each sample was collected in a jar, the pH was read on a digital screen in directly immersing the electrode of the pH meter in the solution after calibrating the pH meter using the standards.

Electrical conductivity

The method described by ISO 7888 was used for the determination of conductivity. It was carried out using a conductivity meter (WTW 315i, Germany) and is expressed in micro siemens per centimeter (µS/cm). The WHO sets 400 µS/cm as the reference limit for electrical conductivity measured at 25 ºC for drinking water.

Turbidity

The turbidity was determined according to the nephelometric method described by ISO 7027. It is expressed in Nephelometric Turbidity Unit (NTU). Turbidity was measured using a turbidimeter (Hach 2100 QIS, China).

Minerals

The minerals present in the water sampled were determined according to the standards mentioned in Table 2. Thus, the trace elements, heavy metals and other minerals were measured by spectrophotometry using a spectrophotometer (ICP Avio 200, USA). This method consisted in measuring the optical density of chemical substances according to their absorption wavelength. It is a method that is simple, precise and fast at the same time, which makes it possible to reduce errors that could be due to manipulations (Rodier *et al*., 2009) [10].

Data processing

The data processing was carried out using the Excel 2019 spreadsheet. The measured values were expressed as averages. The means obtained were subjected to a one-way analysis of variance (ANOVA). When the ANOVA test revealed a significant difference at the 5% threshold in the means, a Tukey post-ANOVA test was performed to locate the level of difference.

Results

Physical Parameters

pH

The different water samples taken at Daloa have a pH that varies between 3.98 and 6.30 (Table 3). The standard required for the pH in drinking water is between 6.5 and 8. Spring water taken from Pastoral Institute district and well water taken from ORLY 1 district are more acidic than the others. On the other hand, the water distributed by SODECI is closer to the standard.

Electrical conductivity

The value of the water samples varies between 72.80 µS/cm and 681 µS/cm (Table 3). The standard required by the WHO (2000) [11].is a conductivity of less than 400 µS/cm measured at 25 °C. However, fountain water from GARAGE district and wells from ORLY 1 district have high conductivity with respective values of 451.33 µS/cm and 681 µS/cm compared to the other types of water sampled.

Turbidity

Table 3 presents the turbidity values of drinking water in Daloa. Almost all of the water samples do not meet the standard set by the WHO (2017) [1] which is on average or less than 0.2 NTU, except for the spring water in the EVECHE district which has a turbidity of 0.17 NTU below WHO (2017) [1] standard.

Chemical parameters

Trace elements

Table 4 shows the concentration of iron, manganese and zinc present in the water consumed in Daloa. These results show that the manganese concentration complies with the WHO standard (Mn ≤ 0.4 mg/L) for all the water samples analyzed. The iron concentrations are between 0.003 mg/L and 0.366 mg/L (iron concentration in SODECI water). As for zinc, all the concentrations are less than 0.001 except for the ORLY 2, EVECHE and TAZIBOUO 1 water samples. Statistical analysis revealed that there is no significant difference between the zinc values for all water consumed in Daloa except for spring water in the EVECHE district and fountain water in the ORLY 2 district. The analysis also showed a significant difference between the iron and manganese values of the waters of the sites analyzed.

Heavy metals

The data also showed the presence of heavy metals in the samples tested (Table 5). These are mainly arsenic, copper, cadmium, lead and chromium. For copper, chromium and lead, the concentrations obtained comply with the WHO (2017) [1] standard. However, cadmium records very high values for the water distributed by SODECI (5.32 mg/L). Also, the samples from the Pastoral Institute, TAZIBOUO 1, GARAGE, ORLY 2 and EVECHE show high concentrations of cadmium. Regarding arsenic, the concentrations are high in the water samples from GARAGE, ORLY 1, LABIA, EVECHE and ORLY 2.

Other minerals

Table 6 presents the other minerals present in the water

samples. The results showed that the majority of the other minerals measured all comply with the WHO (2017) [1] standard for which the guide values are specified or recommended with the exception of the aluminum concentration which is high in Institute Pastoral (spring water and wells), ORLY 1 (well water), TAZIBOUO 1 (well water) and water distributed by SODECI in Daloa samples. The data also showed that free chlorine has low concentrations in the samples analyzed except for SODECI water, which is within the range prescribed by the WHO (0.2-5 mg/L). Statistical analysis showed that there is a significant difference at the 5% threshold between the concentrations for each mineral except bicarbonate.

Discussion

This study showed that the pH value of the water consumed in Daloa does not meet the standard required by the WHO (6.5 to 8). The waters of this city are generally acidic. This indicates that these waters are corrosive. Several works in different regions of the country have shown the acidity of the waters. These include the regions of Tiassalé (Oga *et al*., 2009) [12], Katiola (Oga *et al.*, 2010) [13], San-Pédro (Lasm *et al*., 2011) [14] and Daloa (Adjiri *et al*., 2019) [16]. The pH is one of the indicators for knowing the quality of drinking water. Indeed, a low or high pH can promote the development of certain microorganisms or limit the action of chlorine in water (WHO, 2017) [1].

Regarding the electrical conductivity measured at 25 °C, it made it possible to assess the mineralization of the water. It can be noted that of all the samples analyzed, only the water from GARAGE fountain and ORLY 1 wells are mineralized. This result could be explained by the fact that these water samples contain a large amount of dissolved minerals in ionized form.

Designating the cloudiness of water, turbidity is one of the important parameters in drinking water. The turbidity values of the waters sampled in Daloa are higher than the standard prescribed (≤ 0.2 NTU) by the WHO (2017) [1] except for that of the EVECHE district (0.17 NTU). This situation would be due to the absence or malfunction of the filtration device before use of this water. There could also be a hint of dust spurting due to the lack of sanitation in the living environment. Also, visible turbidity reduces the acceptability of the water. Indeed, many consumers associate turbidity with health safety and consider that cloudy water is unfit for consumption (HCSP, 2015) [17]. However, Daloa is not the only city in Côte d'Ivoire with troubled waters. Indeed, the work carried out by Kouadio *et al.* (2020) [18] showed that the turbidity of water in sachets sold in the cities of Korhogo, Bouaké, Daloa, Man, Abengourou, San-Pedro and Abidjan did not comply with the WHO standard. Recently, the work carried out by Kossonou *et al.* (2022) [5] on the waters sold in the city of Man also showed the acidic nature of the waters.

The mineral composition was analyzed during this study. Thus, among the trace elements of the water distributed by SODECI, iron has a concentration of 0.366 mg/L. However, according to the WHO (2017) [1] from a concentration of 0.3 mg/L, iron colors laundry and taps and a taste of iron may be perceptible. This concentration of iron in the water distributed by the SODECI of Daloa could explain the comments of the users of this water who stipulate that it is colored. As for the other water sources found in Daloa, the iron concentration is below this value (0.3 mg/L) which leads to staining of the laundry. Furthermore, zinc is very low in all the samples in this study. As for manganese, the levels found in SODECI water, wells in the Orly 1 and Tazibouo 1 districts are higher than the recommended standard for drinking water (≤0.4 mg/L). This presence of manganese in the water could justify the complaints of certain consumers in connection with the coloring of the water and/or stains on the laundry when using this water from the wells in these areas. Indeed, according to work carried out by Dietrich and Burlingame (2015) [19] when the concentration of manganese is high it casts doubt on the quality of the water, the presence of this mineral acts on the coloring of the water just like iron.

This study revealed the presence of heavy metals whose concentration does not comply with WHO standards. These are arsenic and cadmium. Indeed, the water distributed by SODECI contains a significant amount of cadmium (5.32 mg/L) as well as in the samples from the Institute Pastoral, TAZIBOUO 1, Garage, ORLY 2 and EVECHE. Also, the arsenic concentrations of certain water samples are high, in particular the samples from GARAGE, ORLY 1, LABIA, EVECHE and ORLY 2. According to WHO (2017) [1], cadmium is widely used in steelworks and in the plastics industry. This metal enters the environment through wastewater; diffuse pollution is due to contamination by fertilizers and local air pollution. For Mohod and Dhote (2013) [20], toxic metals are generally present in industrial, municipal and urban effluents. The high concentration measured for these heavy metals in this study could be linked to the presence of industrial activities and municipal effluents in the districts of Garage, ORLY 1 & 2, TAZIBOUO 1, LABIA, EVECHE and Institute Pastoral. However, it has been proven that these heavy metals when inhaled are carcinogenic to humans. For cadmium, the kidney is the main target of its toxicity (WHO, 2017) [1]. Thus, the high concentrations of cadmium and arsenic in drinking water in Daloa can be of concern for the health of consumers.

For all the remaining minerals, the concentrations obtained show that they are not of concern for the health of consumers. Indeed, the values of the concentrations of these minerals were generally in line with WHO standards. However, the aluminum concentrations in the samples from the Institut Pastoral (spring water and wells), ORLY 1 (well water), TAZIBOUO 1 (well water) and the water distributed by SODECI in Daloa are high. The relatively high aluminum content in the water distributed by SODECI could explain consumer complaints following the deposition of aluminum hydroxide flocs and the intensification of the color change in the water due to iron. Also, these deposits are responsible for the cloudiness of these drinking waters.

Table 1: Sampling site and type of water sampled for the study in the city of Daloa

Location	Type of water withdrawn	Quantity
Daloa	SODECI	1.25 L
Pastoral Institute	Well	1.25 L
Pastoral Institute	Spring	1.25 L
Garage	Fountain	1.25 L
Eveche	Spring	1.25 L
Tazibouo 1	Well	1.25 L
Tazibouo 1	Spring	1.25 L
Orly 1	Well	1.25 L
Orly 2	Fountain	1.25 L
Labia	Spring	1.25 L

Table 2: Reference methods for the determination of minerals in water

Minerals	Method references
Iron, Manganese, Zinc, Arsenic, Copper, Cadmium, Lead, Chromium, Calcium, Magnesium, Potassium, Sodium, Aluminum	ISO 11885
Ammonia	Hach 8038
Free chlorine	ISO 7393-2
Chloride	Hach 8113
Bicarbonates	ISO 9963-1
Nitrates	Hach 8039
Nitrites	Hach 8507
Sulfide	Hach 8131
Sulfate	Hach 8551

Source: WHO (2017)

Table 3: Chemical parameters of Daloa waters

Samples	pH	Turbidity (NTU)	Conductivity (µS/cm)
SODECI	6.3a	1.27 c	238.33 c
Well ORL1	3.98 f	8.63 a	681.0 a
Fountain GAR	6.10 ab	0.50 c	451.33 b
Well Pastoral I	5.39 bcd	6.17 ab	179.03 e
Well TAZI 1	4.55 ef	5.77 b	205.0 d
Spring TAZI 1	5.16 cde	0.70 c	123.93 f
Spring EVE	5.35 bcd	0.17 c	129.5 f
Spring LAB	5.32 bcde	2.37 c	72.8 g
Spring Pastoral I	4.95 de	0.82 c	114.23 f
Fountain ORL 2	5.84 abc	0.57 c	89.2 g
Standard (WHO, 2017)	6.5-8	≤ 0.2	< 400

Means followed by the different letters in the same column are statistically different at the 5% level.
ORL1: ORLY 1, GAR: GARAGE, Pastoral I: pastoral institute, tazi 1: tazibouo 1, eve: eveche, lab: labia, orl2: orly 2

Table 4: Trace elements present in the waters of Daloa

	Concentrations en mg/L		
Samples	**Iron**	**Manganese**	**Zinc**
SODECI	0.366 a	0.09 b	< 0.001 b
Well ORL1	0.030 e	0.18 a	< 0.001 b
Fountain GAR	0.004 h	0.00 g	< 0.001 b
Well Pastoral I	0.077 c	0.03 e	< 0.001 b
Well TAZI1 P	0.023 f	0.08 c	< 0.001 b
Spring TAZI1	0.194 b	0.04 d	0.002 b
Spring EVE	0.002 h	0.03 e	0.014 ab
Spring LAB	0.044 d	0.01 fg	< 0.001 b
Spring Pastoral I	0.014 g	0.01 f	< 0.001 b
Fountain ORL2	0.003 h	0.01 g	0.020 a
Standard (WHO, 2017)	NGV	≤0.4	NGV

Means followed by the different letters in the same column are statistically different at the 5% level according to the Tukey test
Orl1: orly 1, gar: garage, pastoral i: pastoral institute, tazi 1: tazibouo 1, eve: eveche, lab: labia, orl2: orly 2, ngv: no guide value

Table 5: Heavy metals present in the waters of Daloa

		Concentrations en mg/L			
Samples	**Arsenic**	**Cadmium**	**Chromium**	**Copper**	**Lead**
SODECI	0.009 c	5.323 a	0.002 cd	0.115 a	< 0.005 a
Well ORL1	0.092 b	0.001 b	0.002 d	0.003 de	< 0.005 a
Fountain GAR	0.239 a	0.005 b	0.003 bc	0.002 e	< 0.005 a
Well Pastoral I	< 0.005 c	<0.007 b	< 0.002 d	< 0.002 e	< 0.005 a
Well TAZI1 P	0.009 c	0.050 b	0.002 d	0.009 c	< 0.005 a
Spring TAZI1	0.011 c	0.011 b	0.002 d	0.005 d	< 0.005 a
Spring EVE	0.041 bc	0.006 b	0.003 b	0.017 b	< 0.005 a
Spring LAB	0.039 bc	< 0.000 b	0.004 a	0.002 e	< 0.005 a
Spring Pastoral I	0.006 c	0.012 b	< 0.002 d	0.002 e	< 0.005 a
Fountain ORL2	0.023 c	0.004 b	0.002 d	0.003 de	< 0.005 a
Standard (WHO, 2017)	<0.01	<0.003	RGV (<0.05)	<2	RGV (<0.01)

Means followed by the different letters in the same column are statistically different at the 5% level according to Tukey's test.
ORL1: Orly 1, GAR: Garage, Pastoral I: Pastoral Institute, TAZI 1: Tazibouo 1, EVE: Eveche, LAB: Labia, ORL2: ORLY 2, RGV: recommended Guide Value

Table 6: Macro-elements present in the waters of Daloa

Samples	NH^{4+}	Free Cl	Cl^-	HCO_3^-	NO_3^-	NO_2^-	S^{2-}	SO_4^{2-}	Ca^{2+}	K^+	Mg^{2+}	Na^+	Al^{3+}
SODECI	0.18 c	0.27 a	24.87 b	32.50 c	< 0.27 g	< 0.02 de	52.0 a	23.33 b	21.04 b	5.0 ef	4.97 a	17.08 d	0.51 c
Well Orly 1	2.36 a	<0.02 b	87.2 a	1.22 g	42.73 a	0.05 a	< 5.0 d	< 2.0 c	11.2 c	39.70 a	3.42 b	85.6 a	1.18 a
Fountain Garage	0.02 d	< 0.02 b	13.1 gh	100.33 a	3.53 f	0.04 bc	< 5.0 d	50.0 a	55.13 a	6.53 b	4.96 a	25.13 b	0.05 i
Well Pastoral I	1.58 b	< 0.02 b	19.99 d	24.63 d	8.50 c	0.04 bc	< 5.0 d	< 2.0 c	7.28 d	6.18 c	2.47 c	14.93 f	0.58 b

Well Tazibouo 1	2.33 a	< 0.02 b	24.13 c	4.83 f	5.57 e	0.02 e	20.0 b	< 2.0 c	3.03 fg	5.46 d	2.65 c	13.29 g	0.33 e
Spring Tazibouo 1	0.07 d	< 0.02 b	14.24 f	1.24 g	8.27 c	0.05 ab	< 5.0 d	< 2.0 c	5.17 e	3.11 h	0.53 e	15.7 e	0.18 f
Spring Eveche	0.05 d	< 0.02 b	12.80 h	14.63 e	9.43 b	0.02 de	< 5.0d	< 2.0 c	2.28 gh	2.97 h	0.58 e	21.8 c	0.10 h
Spring Labia	0.02 d	< 0.02 b	13.44 g	13.29 e	3.70 f	0.04 bc	14.33 c	< 2.0 c	0.71 i	3.84 g	0.68 e	9.11 j	0.36 d
Spring Pastoral I	0.04 d	< 0.02 b	16.03 e	6.12 f	6.90 d	0.03 cd	< 5.0 d	< 2.0 c	1.94 h	5.13 e	1.62 d	11.78 h	0.12 g
Fountain Orly 2	0.02 d	< 0.020 b	8.840 i	42.78 b	< 0.03 g	0.03 cd	< 5.0 d	< 2.0 c	3.96 f	4.91 f	0.81 e	10.64 i	0.02 j
Standard (WHO, 2017)	NGV	0.2-5	NGV	NGV	≤50	≤3	NGV	NGV	NGV	NGV	NGV	NGV	≤0.2

Means followed by the different letters in the same column are statistically different at the 5% level according to Tukey's test.
Pastoral I: Pastoral Institute

Conclusion

The results of the physico-chemical parameters of the samples analyzed do not always comply with the recommendations of the standards prescribed by the WHO. In addition, the concentrations of heavy metals, specifically arsenic and cadmium, in the waters of TAZIBOUO 1, ORLY 1 & 2, Garage, Eveche and the Pastoral Institute are high. Also the water distributed by SODECI contains a significant amount of cadmium and manganese. It would be beneficial to treat this water before use for human consumption. The turbidity of this drinking water, except for the sample from the EVECHE district, is above the norm. In view of the above, since the most important effect related to turbidity is probably its ability to protect microorganisms against disinfection, bacteriological tests should be carried out on the different types of water available in Daloa and also make users aware of the need to treat this water before human consumption.

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