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Physico-chemical Characterization of Well and Borehole Water in the Municipality of Seme-Podji

Gbèssohèlè Justin Behanzin[1], Alphonse Sako Avocefohoun[2,3,*], Mahoudjro Theotime Francis Hounsou[2,3], Sènan Vodouhè[2], Papin Sourou Montcho[3], Sagbo Damien Zannou[1], Elie Sogbochi[3], Alassane Abdou Karim Youssao[3], Alphonse Sezan[1]

[1]Biomambrane And Cell Signaling Laboratory, Faculty Of Science And Technology, University Of Abomey Calavi, Benin
[2]Applied Biology Research Laboratory, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Benin
[3]Applied Chemistry Research and Study Laboratory, Polytechnic School of Abomey-Calavi,
University of Abomey-Calavi, Cotonou, Benin
*Corresponding author: alphsakoav@gmail.com

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Abstract: Water is essential for life on earth. The body's main source of water is drinking water. Water used for food must not contain any pathogenic germs or toxic elements. The aim of this study is to assess the physico-chemical parameters of well and borehole water in the commune of Seme-Podji, in order to raise awareness. A field survey was therefore carried out in 60 households in 13 neighborhoods in the 4 arrondissements of the municipality, most of which are not covered by the SONEB distribution network, by means of questionnaires and direct observation in the field. The information collected made it possible to identify the sources of water pollution, the treatments given to the water before it is consumed, the method of storage, the frequency and method of cleaning the storage tanks and the diseases affecting the population in these areas. A total of twenty-three water samples, including 12 from wells and 11 from boreholes, were taken and analyzed for physico-chemical quality using standardized methods at the DNSP-affiliated Water and Food Quality Control Laboratory in Xwlacodji. The R2V7LENT analysis results show that 28.26% of these waters have unsatisfactory organoleptic characteristics. These waters are generally very "soft" and "aggressive", with a significant mineralogical imbalance, characterized by a deficit of F^-, Ca^{2+}, Mg2+; an excess of NO_2^- content and a possible additive effect of NO_2^- and NO_3^-, which is one of the most serious issues from a nutritional point of view. The water studied is of poor quality, even unfit for consumption. They are a potential source of waterborne disease epidemics. These waters need to be treated before consumption in order to remove the threat, they pose to public health.

Keywords: *Water, wells, boreholes, diseases, properties, physico-chemical*

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1. Introduction

According to the WHO, water intended for drinking must be clear, colorless, odorless and pleasant to the taste; it must not contain any pathogenic germs or toxic elements [1]. In developed countries such as the United States, the average person uses 600 liters of water a day; in France, a person consumes around 150 liters of water a day, while the average African makes do with 10 to 20 liters a day. This is a long way from the minimum 80 liters of water recommended by the WHO for a person's daily needs (household, drinking, hygiene, etc.) [2]. Water use differs from one country to another.

Water contamination is the main source of water-borne diseases such as typhoid fever, gastroenteritis, intestinal parasites, lead poisoning, cyanosis and fluorosis. Drinking water, a key factor in the prevention of water-borne diseases, must be given special attention.

Water is a crucial issue in developing countries. Hygiene, the potability of water and sanitation are directly linked to the socio-economic level of these countries. The traditional method of treating drinking water, chlorination, used by some households, is sometimes not very effective, given the resistance of certain pathogens to disinfection [3].

The process of transporting water in dirty containers, the use of tree branches to stabilize the water during transport, storage in dirty containers, poor management of household waste, the presence of septic tanks, lack of treatment, poor hygiene and non-compliance with sanitation standards around these water points all make it easier for them to become contaminated [4,5].

Some of the research carried out on groundwater quality has concluded that the pollution of this water comes from both geological and anthropogenic sources. One form of this anthropogenic pollution, which is generally diffuse, is the contamination of these water points by the infiltration or run-off of rainwater leached from areas of industrial activity, farms or market gardens using chemical fertilizers [6,7,8].

In the municipality of Seme-Podji, the issue of access to drinking water and hygiene and sanitation systems is a major concern for the entire population of the municipality. Of the 38 villages and city districts in the Commune, only 22 have water from the National Water Company of Benin (SONEB) and the majority are concentrated in the arrondissements of Agblangandan and Seme-Podji, [9]. In response to the shortage of drinking water, people in districts not fully covered by the SONEB drinking water supply network resort to wells (traditional or modern), especially in areas where water is readily available, and/or to private boreholes to obtain drinking water. While these facilities have the advantage of solving the problem of water availability, the quality of the water is often not guaranteed, which has consequences for health. The aim of this study is to assess the physico-chemical quality of water from wells and boreholes in the commune of Seme-Podji.

2. Material and Methods

2.1. Biological Material

Biological material consists primarily of twenty-three (23) water samples, including 12 well water and 11 well water samples.

2.2. Different Stages of the Research Process

To achieve the objective of our study, the research was conducted in three phases: literature review, field work and laboratory analysis.

2.3. Literature Review

It enabled us to gather preliminary information relating to the research topic, in order to better define its aspects and contours. The documents consulted included dissertations and theses, study reports, articles, books and websites.

2.4. Fieldwork

The fieldwork was carried out in three phases: the exploratory phase, the actual survey phase and the sampling phase.

- The exploratory phase involved exploring the research area and making direct observations to establish the relevance of the problem raised. It also enabled the study population to be selected.
- The actual surveys were carried out in the households concerned by this study. The survey form included information on the water supply, the perception of drinking water quality by the target households, and the factors that could contribute to water contamination at the various water points. This sheet is often sent to the heads of households.
- During the sampling phase, 23 water samples were taken from 12 wells and 11 boreholes (5 in compliance and 6 not in compliance with the standard). The water samples required for the physico-chemical analysis were taken using the method described by RODIER in 1978, in 500 ml bottles [10]. The well water was taken from the wells of each household and put directly into bags sterilized up to ¾ in compliance with the rules of asepsis. Borehole water samples were taken from the most frequently used taps in each household.

2.5. Physico-chemical Analysis of Water Samples

2.5.1. Measuring Physical Parameters

The physical parameters determined are: temperature, pH, electrical conductivity, TDS, salinity, turbidity and color. These parameters are measured using various types of equipment and appropriate analysis methods.

2.5.2. Electrometric Method

2.5.2.1. Temperature Measurement

Temperature is determined by the electrometric method. This is done using a temperature probe which is connected to the pH meter after calibration with two solutions (pH4, pH7) [11].

2.5.2.2. Determination of Electrical Conductivity

The electrical conductivity of samples is measured using a WAG TECH conductivity meter. It is determined by measuring the electrical resistance of the solution. A voltage is applied between two electrodes immersed in the sample, and the drop in voltage due to the resistance of the solution is used to calculate the conductivity per centimeter. The unit of measurement for conductivity is µS/cm [10].

2.5.2.3. Determining Salinity

The high concentration of dissolved salt gives the water a high conductivity. The salinity of water samples is estimated using electrical conductivity. It is expressed in S ‰ and is obtained by comparing the conductivity result of the sample with the conductivity of the 0.01N KCl solution according to the following equation:

$$\text{Salinity} = \frac{\text{Conductivity of the sample at } 25^\circ\text{C}}{\text{Conductivity of a } 0.01\text{N KCL solution at } 25^\circ\text{C}}$$

2.5.2.4. Determining the Color

Color is expressed as "apparent" or "true" color. Apparent color includes that due to suspended matter. It is said to be true when the dissolved substances add their own coloring. The sample is centrifuged and measured according to the platinum-cobalt (Pt/Co) scale. By filtering or centrifuging the sample, the true color is determined. The reading is obtained at 450 nm.

2.5.2.5. Potentiometric Method (pH measurement)

The pH of the samples is determined using an OHAUS Model ST10 pH meter by the potentiometric method. This method is based on measuring the potential difference between a glass electrode and a reference electrode (calomel - saturated KCl) immersed in the same solution. This potential difference is a linear function of the pH of the solution [10].

2.5.3. Photometric Method

2.5.3.1. Determination of Turbidity

The light beam passes horizontally through the bowl containing the sample, part of which is scattered by the Tyndall effect by means of the suspended particles. The electron photomultiplier located at an angle of 90° to the light beam captures scattered photons and transforms this light energy into an electrical signal whose potential is a function of turbidity [12].

2.5.3.2. Measurement of Chemical Parameters

The chemical parameters determined are: nitrates (NO_3^-), nitrites (NO_2^-), ammonium (NH_4^+), ortho-phosphates (PO_4^{3-}), fluorides (F^-), chlorides (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), total hardness (TH), carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-). The methods of determination shall be colorimetric with molecular absorption spectrophotometry and titrimetric methods. The titrimetric method is used for ions, Cl-, Ca2+, Mg2+, TH, CO32-and HCO_3^-. The other chemical parameters (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, F^-) are measured using a molecular absorption spectrophotometer of the HACH LANGE DR./3900 type with an accuracy of 95 to 99%. The procedure is identical for these ions concerned (NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, F^-).

2.5.4. Assay by Molecular Absorption Spectrometry

2.5.4.1. Determination of Nitrites by the Diazotization Method

The Diazotation method is used for the determination of nitrites in water. The nitrite in the sample reacts with sulfuric acid to form an intermediate diazonium salt. The latter combines with chromotropic acid to produce a pink complex whose intensity is directly proportional to the concentration of nitrite in the solution. The reading is obtained at 507 nm.

2.5.4.2. Determination of Nitrates by the Method of Cadmium Reduction

The Cadmium reduction method is used for the determination of nitrates. The range of application is 0.3 to 30.0 mg/l NO_3^-. Higher concentrations can be determined by dilutions. Cadmium reduces nitrate in the sample to nitrite. The nitrite ion reacts with sulfuric acid to form an intermediate diazonium salt. This salt reacts with gentisic acid to form an amber-colored complex proportional to the amount of nitrate in the water. The reading is obtained at 500 nm.

2.5.4.3. Ammonium Nessler assay

Ammonium was determined by the Nessler method. During the assay, the mineral stabilizer complicates the hardness in the sample. The dispersing agent, polyvinyl alcohol, promotes coloring during the reaction of NESSLER's reagent with ammonium ions. A yellow color is formed which is proportional to the concentration of ammonia. The reading is obtained at 425 nm.

2.5.4.4. Determination of Ortho-Phosphates by Ascorbic Acid Reduction Method

The ascorbic acid reduction method is used for the determination of ortho-phosphates. The ortho-phosphate reacts in an acid medium with the molybdate in the Phos Ver 3 reagent to form a phosphomolybdate complex. This complex is reduced by the ascorbic acid contained in the Phos Ver 3 reagent, giving an intense molybdenum blue coloration proportional to the concentration of phosphonate present in the initial sample. The reading is obtained at 890 nm.

2.5.4.5. Determination of Fluorides by the SPADNS Method

The SPADNS method for the determination of fluoride implements the reaction of fluoride with a zirconium red coloring solution. The fluoride combines with a portion of the zirconium to form a colorless zirconium-fluoride complex, producing a decrease in red color proportional to the fluoride concentration. The reading is obtained at 580 nm with a molecular absorption spectrophotometer DR. 3900.

2.5.4.6. Determination of Chlorides by the Mohr Method

- Procedure: 100 ml of the sample to be analyzed were withdrawn from a 250 ml Erlenmeyer flask and 3 drops of 10 % potassium chromate (K_2CrO_4) were added by pipette, giving a yellowish color. The silver nitrate solution ($AgNO_3$ at 0,1N) was then titrated by gradual addition using a digital burette until a reddish-brown coloration was obtained.
- Expression of results: the chloride concentration is obtained and expressed in mg/l as:

$$\left[Cl^-\right] = \frac{(\mathrm{Vs} - \mathrm{Vb})\,\mathrm{x}\,\mathrm{f}}{\mathrm{Vo}}(\mathrm{mg/L}) \qquad (1)$$

V_s is the volume of $AgNO_3$ of the titrating solution required for the titration of the sample;

V_b is the volume of silver nitrate titrating solution used for the blank;

V_o is the Volume of the sample;

f is the conversion factor of the $AgNO_3$ titer of 35 453 mg/mol [10].

2.5.4.7. Calcium Ion Determination by Titrimetric EDTA Method

- Procedure: 2 ml of NaOH, 10 ml of buffer solution at pH=12 and approximately 0.2 g of the murexide indicator were added to 50 ml of sample and titrated with EDTA using a digital burette until the colour changed from pink to purple. The volume of EDTA solution added was then recorded as VE and the level of calcium ions in the solution was calculated.

- Expression of results: the calcium content [Ca^{2+}], expressed in mg/l, is given by the equation [13].

$$\left[Ca^{2+}\right] = \frac{\mathrm{C1.VE}}{\mathrm{V0}}.100\left(\mathrm{mg/L}\right) \quad (2)$$

C_1: The concentration expressed in m mol/L of the EDTA solution;

V_E: The volume in milliliters of the EDTA solution used for the assay;

V_0: The volume in milliliters of the test sample.

2.5.4.8. Determination of Magnesium Ions Using the EDTA Titrimetric Method

Magnesium hardness is, by definition, the concentration of magnesium salt. It is deduced from the relationship between total hardness and the sum of calcium and magnesium hardness [10].

$$TH_{Mg^{2+}} = \frac{\mathrm{TH} - 2,497 \times \mathrm{THCa}^{2+}}{4,116}\left(\mathrm{mg/L}\right) \quad (3)$$

TH: Total hardness;
TCa^{2+}: Calcium hardness;
TMg^{2+}: Magnesium hardness.

2.5.4.9. Determination of Total Hardness by the EDTA Titrimetric Method

- Procedure: Three drops of NET powder (Eriochrome Black T) were added to 10 ml of sample water heated in a water bath to a temperature of approximately 60°C, followed by 4 ml of the pH=10 buffer solution. The solution obtained was then titrated with EDTA until it turned dark blue. The volume of EDTA solution added was then recorded as VE.
- Expression of results: the overall calcium and magnesium content Ca+Mg (TH), expressed in milligrams per liter, is given by the equation:

$$\mathrm{TH} = \frac{\mathrm{C1} \times \mathrm{VE}}{\mathrm{V0}} \times 100\left(\mathrm{en\ mg/L}\right) \quad (4)$$

C_1 = Concentration of EDTA titrant solution expressed in m mol/l;

V_E =Volume in ml of the EDTA solution used for titration;

V_0=Volume of sample assayed in ml [10].

2.5.4.10. Determination of Bicarbonates by the Volumetric Method Using Sulfuric Acid (H_2SO_4)

- Procedure: 50 ml of the water to be analyzed was taken in a 250 ml Erlenmeyer flask and 2 drops of the 0.5% methyl orange solution were added. A yellow coloration appeared; the sample was then titrated by gradually adding a 0.02N sulfuric acid solution (H_2SO_4) to the Erlenmeyer flask until it turned orange-yellow (pH= 4.3) using a digital burette. The number of milliliters of strong acid solution poured was then noted as V_1.
- Expression of results:

$$[\mathrm{HCO_3}^-] = \frac{\mathrm{N\ x\ V1x50000}}{\mathrm{V0}}\left(\mathrm{en\ mg/L}\right) \quad (5)$$

N: normality of the H_2SO_4 solution used;
V_1: Volume of H_2SO_4 titrated in mL;
V_o: Volume of sample in mL;
50 000: weight of one $CaCO_3$ equivalent expressed in mg.

2.6. Statistical Analysis

Data analysis and statistical processing are made possible by:

- MICROSOFT EXCEL software used for coding survey data and laboratory analysis results;
- MINITAB version 17 and GRAPHE PAD PRISME7 software for producing the various graphical documents;
- ANOVA test for analysis of variance;
- TUKEY'S multiple comparison test to determine the differences between the samples.

Differences were considered significant when $p<0.05$.

3. Results

Table 1. Qualité physico-chimique des échantillons

Value of N	Ratings
N’ < M’	Satisfactory physico-chemical quality
N’ ≥ M’	Unsatisfactory physico-chemical quality

- M': the upper limit of the standard values;
- N': the value of the physico-chemical analysis parameter

3.1. Physico-chemical Analysis of Well and Borehole Water Samples

3.1.1. Physical Parameters

The temperature and pH of the water in the sampled wells and boreholes did not vary significantly from one district to another ($p>0.05$). On the other hand, a statistically significant difference was noted between the districts for the conductivity, turbidity and color of the water ($p<0.05$).

In the same column, averages followed by different letters are significantly different ($p<0.05$).

3.2. Chemical Parameters

The results of the chemical analysis of the well water sampled reveal the presence of nitrites in worrying levels. Indeed, 58.33% of the wells sampled had NO_2 levels > 0.10 mg/L, the standard recommended by the WHO and Benin for drinking water. This high nitrite content was mainly observed in wells that did not comply with sanitation standards in all the targeted districts. The water studied had nitrate levels below the recommended standard of 45 mg/L in drinking water. The $NH4^+$ and Cl^- levels recorded in these waters are higher than the quality references for ammonium in groundwater, usually < to 0.2 mg/L [14] and chlorides in running water, usually < to 25 mg/L. The variation in average fluoride levels obtained is below concentrations of between 0.5 mg/L and 1.5 mg/L, constituting doses that ensure protective effects. Finally, the water analyzed showed unbalanced calcium and magnesium concentrations.

Analysis of this histogram shows that of the 11 water samples analyzed, 43.33% are of unsatisfactory physico-chemical quality, and 56.66% of satisfactory physico-chemical quality.

Of the 12 samples analyzed, 58.33% were of unsatisfactory physico-chemical quality, compared with 41.67% of satisfactory physico-chemical quality.

Table 2. Mean values and standard deviations of physical parameters of well and borehole water (Time: Temperature; pH: Hydrogen potential; EC: Electrical Conductivity; Turb: Turbidity; Color)

Boroughs	Parameters				
	Time (°C)	PH	CE (µS/cm)	Turb (NTU)	Color (PtCo)
	Wells Boreholes	Wells Boreholes	Wells Boreholes	Wells Boreholes	Wells Boreholes
Aholouyeme	28.17±0.32 a 27.73±0.23 a	6.76±0.32 a 5.20±0.55 a	204.1±85.66 a 378.77±446.15 b	8.93±8.6 b 2.67±1.54 b	13,33±5,86 a 10,33±6,87 b
Djerebe	28.33±0.45 a 27.73±0.15 a	6.72±0.29 a 4.82±0.50 a	306.2±121.23 a 211.57±127.96 b	10.73±13.5 b 1.02±0.1 a	24,33±30,92 b 2,33±0,58 a
Ekpe	28.57±0.42 a 28.35±0.07 a	6.66±0.15 a 6.78±0.39 a	209.83±60.30 a 345.5±12.02 a	4.05±2.8 b 1.66±0.78 a	19±4 a 40±28,99 b
Tohoue	29±0.1 a 28±0.1 a	6.55±0.08 a 5.52±0.9 a	302.77±140.4 a 172.5±29.51 a	15.67±25.05 b 1.04±0.08 a	20±26 b 0,67±0,6 b
Normes	~ 25	6.5 – 8.5	2000	5	15

Table 3. Average values for chemical parameters in well and borehole water

Parameters	Unit	Average values by sampling district								Standards
		Aholouyeme		Djeregbe		Ekpe		Tohoue		
		Wells	Boreholes	Wells	Boreholes	Boreholes	Boreholes	Wells	Boreholes	
Nitrites	mg/L	0.15	0.02	0.2	0.01	0.2	0.004	0.15	0.03	0.1
Nitrates	mg/L	11.84	14.2	15.8	7.19	5.52	5.6	9.46	79	45
Ammonium	mg/L	0.2	0.07	0.12	0.03	0.3	0.14	0.04	0.01	0.5
Ortho-phosphates	mg/L	0.11	0.04	0.45	0.04	0.55	0.8	0.31	0.9	5
Fluorides	mg/L	0.2	<0.01	<0.01	<0.01	0.1	0.3	<0.01	0.1	1.5
Chlorides	mg/L	42	67.67	73.33	38.67	55	56	65.33	35.33	250
Calcium	mg/L	20	20,3	22,27	4,93	17,2	13,2	15,54	6,8	100
Calcium	mg/L	3,4	10,80	8,31	3,4	4,92	7,02	6,37	3,23	50
Hardness	mg/L $CaCO_3$	64	76.33	90	79	63.33	62	65.33	30.33	200
Bicarbonates	mg/L	85.76	52.46	63.03	52.05	72.39	101.87	78.08	49.61	-

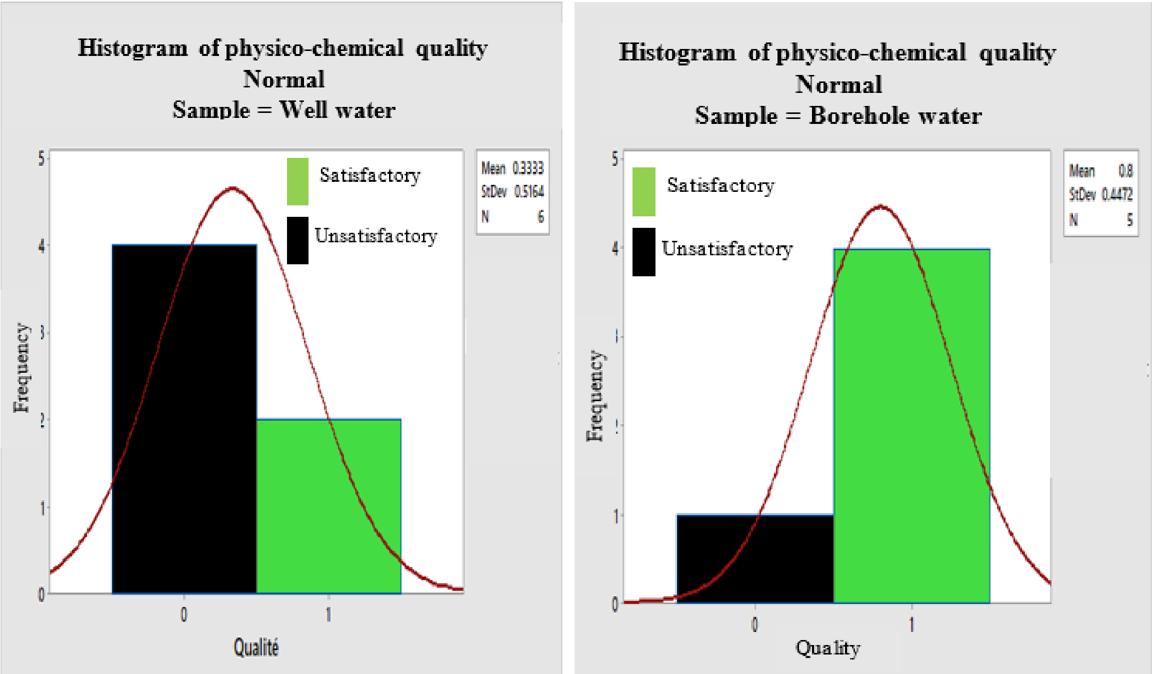

Figure 1. Histogram of the physico-chemical quality of water samples from wells and boreholes complying with sanitation standards

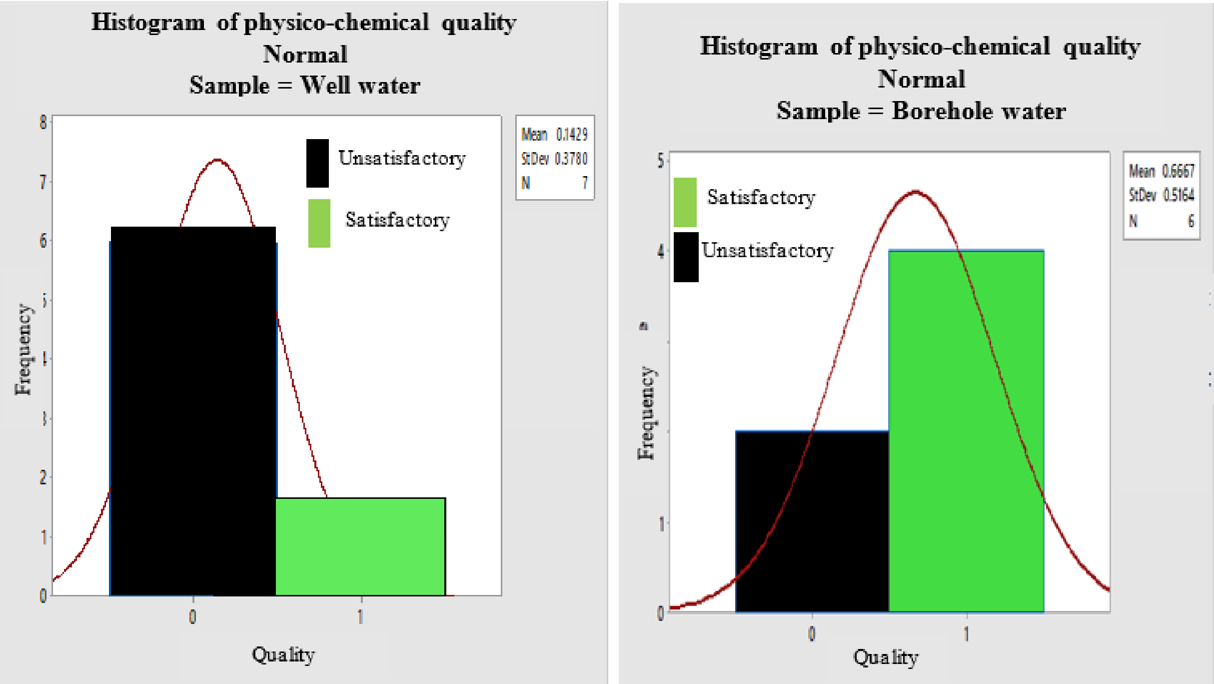

Figure 2. Histogram of the physico-chemical quality of water samples from wells and boreholes that do not comply with sanitation standards

4. Discussion

The results of the physico-chemical analysis revealed a high temperature in all the waters studied, with average values of between 27.73°C and 29°C, above the acceptable limit of 25°C recommended by the WHO. These values recorded in Seme-Podji are similar to those of Dovonou and *al.* in 2018 [15] in the same commune, Lagnika and *al.* in 2014 [6] in Pobe and Nduka and Orisakwe in 2007 [16] in Warri, Nigeria, who recorded average temperatures of between 27°C and 30°C for the well water studied. The high temperatures found in the commune of seme-Podji may reflect the depth of the wells and boreholes (1 to 20m) and be explained by the influence of the ambient heat on the water taken. It should be noted that at temperatures above 28°C, water is a good growth medium for micro-organisms, while at the same time it can intensify tastes and odors as well as a change in color and turbidity [17]. Based on the temperature standards provided by the WHO and Benin, 100% of the water analyzed is unfit for consumption. In addition, 56.52% of the water samples had a pH within the regulatory range for drinking water ($6.5 < pH < 8.5$) and 43.48% of the water had a pH between 4.5 and 5.9, meaning that it was acidic and did not comply with the standards. These values are close to those of Dovonou et *al.* in 2018 [15], who obtained pH values in line with the standard set for drinking water quality, unlike the results of Akodogbo and *al.* in 2005 in Porto-Novo, who obtained pH values ranging from 4-6[18]. The acidity of these pH values is thought to be due to the quality of the subsoil and the corrosion of the cement concrete used to protect the walls of these water points. A pH below 6, as recorded during our sampling, reflects the naturally corrosive state of the water. It is important to note that 82.61% of our water tested is "very soft", 13.04% is only "soft", and 4.35% is "moderately hard". Very soft" water combined with acidic water results in water that is.

The consumption of aggressive water constitutes a real danger to public health, as it can lead to the dissolution of certain metals in more toxic ionic form, such as lead from pipes, which, through a cumulative effect, has a strong toxicological impact on human health [19]. These waters range from low mineralization (172.5µS/cm) to high average mineralization (378.77µS/cm). This character of the waters reflects the presence of an average quantity of mineral salts in the waters studied and would be explained by the nature of the substratum in the study region, which appears to result from the leaching of the reservoir rock within which the waters stayed [7]. With reference to Benin's standards for drinking water, 12.5% of the water analyzed was poorly mineralized, 62.5% was moderately mineralized and 25% had a high level of mineralization, which appears to contribute to the homeostasis of humans and children. Turbidity and color exceeded the standard in 21.74% and 34.47% of the water tested, respectively. These results from Seme-Podji are relatively high compared with the results of Hachemaoui in 2014 [12] in Tlemcen and HOTEYI and *al.* in 2014 [20] in Porto-Novo, who found all the waters studied to be colorless and clear. These turbid and colored waters are unsuitable for consumption and could be used as drinking water. The results of the chemical analysis of the well water sampled reveal the presence of nitrites in worrying levels. Indeed, 58.33% of the wells sampled had NO_2 levels > 0.10 mg/L, the standard recommended by the WHO and Benin for drinking water. This high nitrite content of between 0.15 mg/L and 0.351 mg/L was mainly observed in wells that did not comply with sanitation standards in all the targeted districts. Our results corroborate those of parallel studies conducted by Dovonou and colleagues [15] in the same commune, Degbey and colleagues [5] in an occupational setting in Godomey, and Ayad [21] in d'el-harrouch in Algeria. A nitrous nitrogen content of more than 0.10 $mg.L^{-1}$ in drinking water may indicate the presence of water rich in decomposing organic matter associated with the degradation of fertilizers [14][10]. Nitrite formation could also be the result of bacterial contamination of the water, which reduces nitrates to nitrites before they are ingested [5][6]. Nitrites are toxic to the human body, and this toxicity is very significant due to their oxidizing power. Consumption of these waters can lead to the risk of methemoglobinemia in bottle-fed infants, formula-fed children and pregnant women. This is because nitrites in vivo lead to changes in the properties of hemoglobin in the blood. This toxic effect, also known as "infant cyanosis", leads to a reduction in the blood's ability to transport oxygen to tissues, which can cause death by asphyxiation [14]. Nitrites can also impair human thyroid function by causing thyroid enlargement or goiter, and can also combine with amines to form nitrosamines, which are suspected carcinogens (stomach cancer in adults). These observed nitrite levels confirm the microbiological pollution of the water studied. According to RODIER and his colleagues, water containing nitrites should be regarded as suspect because they are often associated with a deterioration in microbiological quality [10]. According to the standards applied to drinking water, 34.78% of our water submitted for analysis is considered suspect. The nitrate levels in the water studied were below the recommended standard of 45 mg/L in drinking water. However, a possible additive effect of nitrites and nitrates was noted in 66.67% of the well water analyzed. This contamination of wells by nitrites and nitrates is also a very worrying public health problem in Benin, because of the abusive use made of it by the population. It should also be stressed that there is still a residual risk of pollution in 17.39% and 82.61% of our water tested for NH_4^+ and Cl^- respectively, given that the levels of these ions recorded in these waters are higher than the quality references for ammonium in groundwater, usually < 0.2 mg/L [14] and chlorides in running water, usually < 25 mg/L [10]. Consumption of these waters of dubious quality constitutes a health hazard for the population in the areas concerned. Because of its link with health, the WHO sets a quality limit of 1.5 mg/L for fluoride in drinking water, and considers that concentrations of less than 0.5 mg/L indicate a lack of fluoride for the prevention of dental caries [22]. The variation in average fluoride levels obtained (between <0.01 mg/L and 0.302 mg/L) is below concentrations of between 0.5 mg/L and 1.5 mg/L, which are doses that ensure protective effects. Our results are in line with those of Hoteyi and colleagues [20] in Porto-Novo and LANJRI [23] in Tangiers, who obtained fluoride levels almost in the same range in almost all the waters analyzed. When taken in moderation, fluoride is a trace element with beneficial effects: it hardens tooth enamel and strengthens the skeleton. The fluoride deficiency found in our water can increase the risk of dental caries, particularly in young children whose teeth are still forming (infants and children under 12), who are sensitive populations. In fact, our analyzed waters show unbalanced concentrations of calcium and magnesium. This can be explained by the natural structure of the Seme-Podji aquifer (soil poor in certain essential minerals). By analogy, long-term exposure to this deficiency can lead to fluorosis. Finally, we cannot overlook the fact that bicarbonate ions dominate at least 75% of our samples, so they are not in calco-carbonic balance and have a limited buffering effect. HCO_3^- ions are the mainstay of the blood's buffering system, so drinking these waters may not provide the alkalinizing elements needed for good health, particularly in people with an overly acidic background.

5. Conclusion

The water analyzed was of unsatisfactory physico-chemical quality, with chemical contamination of well water and boreholes being widespread. 28.26% of the water samples analyzed had unacceptable organoleptic characteristics (i.e. 41.67% of the wells and 14.85% of the boreholes investigated); 51.14% of the water analyzed was of unsatisfactory physico-chemical quality (i.e. 75% of the wells and 27.27% of the boreholes investigated); 75.18% of the water monitored was of unsatisfactory hygienic or microbiological quality (95.83% of the wells and 54.54% of the boreholes). Overall, the quality of this water is poor, regardless of the measures taken. Overall, it is "very soft" and "aggressive" and can lead to the dissolution of ionized metallic particles, particularly lead, which, through a cumulative effect, becomes neurotoxic and reprotoxic for humans. These waters have a mineralogical imbalance characterized by a deficit of F^-, Ca^{2+} and Mg^{2+}, an excess of NO^{2-}, and a possible additive effect of NO^{2-} and NO^{3-}, correlated with harmful effects on health, particularly in infants and pregnant women. Further studies are needed to identify more dangerous pollution parameters such as pesticides, heavy metals and drug residues, and also to assess the impact of storage equipment on the quality of drinking water.

References

[1] WHO, “How Well Do Health Systems Perform,” *World Heal. Rep. 2000*, pp. 1–206, 2000, [Online]. Available: http:// www.who.int/ whr/2000/en/whr00_en.pdf.

[2] R. TREMBLAY, Diane-Gabrielle et TREMBLAY, “Compétitivité urbaine à l’ère de la nouvelle économie: Enjeux et défis,” *PUQ*, 2011.

[3] World Health Organization, “Global status report on alcohol 2004,” *Dep. Ment. Heal. Subst. Abus.*, 2004.

[4] M. A. Bhosale, R. R., Kumar, A., Van Den Broeke, L. J., Gharbia, S., Dardor, D., Jilani, M., ... & Tarsad, “Solar hydrogen production via thermochemical iron oxide–iron sulfate water splitting cycle.,” *Int. J. Hydrogen Energy*, vol. 40, no. no 4, pp. 1639-1650., 2015.

[5] C. Dégbey, C., Makoutode, M., Fayomi, B., & De Brouwer, “La qualité de l’eau de boisson en milieu professionnel à Godomey en 2009 au Bénin Afrique de l’Ouest.,” *J. Int. Santé au Trav.*, 2010.

[6] M. Lagnika, M. Ibikounle, J. C. Montcho, V. D. Wotto, and N. G. Sakiti, “Caractéristiques physico-chimiques de l’eau des puits dans la commune de Pobè (Bénin, Afrique de l’ouest),” *J. Appl. Biosci.*, vol. 79, no. 1, p. 6887, 2014.

[7] N. Nouayti, D. Khattach, and M. Hilali, “Assessment of physicochemical quality of groundwater of the Jurassic aquifers in high basin of Ziz (Central High Atlas, Morocco),” *J. Mater. Environ. Sci.*, vol. 6, no. 4, pp. 1068–1081, 2015.

[8] A. S. Avocefohoun, B. A. Gbaguidi, H. Sina, O. Biaou, C. S. Houssou, and L. Baba-Moussa, “Fluoride in Water Intake and Prevalence of Dental Fluorosis Stains among Children in Central Benin,” *Int. J. Med. Res. Heal. Sci.*, vol. 6, no. 12, pp. 71–77, 2017, [Online]. Available: www.ijmrhs.com.

[9] H. Valette, F. Gangneron, and A. Bonnassieux, *L'intégration et la mise en œuvre des principes marchands dans le secteur de l'eau en milieu rural et semi-urbain béninois*, no. 45. 2017.

[10] L. R. Jean Rodier, C Geoffray, *L'analyse de l'eau: eaux naturelles, eaux residuaires, eau de mer: chimie, physico-chimie, bacteriologie, biologie*, Dunod. 1978.

[11] D. Diallo, C. Sogn, F. B. Samaké, B. S. Paulsen, T. E. Michaelsen, and A. Keita, "Wound healing plants in Mali, the Bamako region. An ethnobotanical survey and complement fixation of water extracts from selected plants," *Pharm. Biol.*, vol. 40, no. 2, pp. 117–128, 2002.

[12] B. HACHEMAOUI, "QUALITE PHYSICO-CHIMIQUE DE L'EAU DESSALEE ET TRAITEE PAR LA STATION DE DESSALEMENT DE L'EAU DE MER DE SOUK TLATA-TENEURS EN BORE, NITRITES, NITRATES ET METAUX LOURDS," 2014.

[13] M. Ladjal, M. Bouamar, Y. Brik, and M. Djerioui, "A Decision Fusion Method Based on Classiication Models for Water Quality Monitoring A decision fusion method based on classification models for water quality monitoring," pp. 0–17, 2021.

[14] OMS, *Directives De Qualité Pour L ' Eau De Boisson*. 2017. [Online]. Available: http:// apps.who.int/ iris/ bitstream/ 10665/ 258887/1/9789242549959-fre.pdf?ua=1.

[15] F. E. Dovonou, A. Alassane, V. N. Adjahossou, B. Agbodo, R. Djibril, and D. Mama, "Impacts de l'assainissement autonome sur la qualité des eaux de puits dans la Commune de Sèmè-Podji (Sud-Bénin)," *Int. J. Biol. Chem. Sci.*, vol. 11, no. 6, p. 3086, 2018.

[16] J.K.C. NDUKA and O.E. ORISAKWE, "HEAVY METAL LEVELS AND PHYSICO – CHEMICAL QUALITY OF POTABLE WATER SUPPLY IN WARRI, NIGERIA.," *J. Anal. Environ. Cult. Herit. Chem.*, vol. 35, no. 33, pp. 10563–10565, 2007.

[17] Z. C. Koudenoukpo *et al.*, "Caractérisation physico-chimique d'un système lotique en région tropicale : la rivière Sô au Sud- Bénin, Afrique de l'Ouest.," *J. Appl. Biosci.*, vol. 113, no. 1, p. 11111, 2017.

[18] H. AKODOGBO, "Contribution à l'amélioration de la qualité de l'eau à usage domestique dans le 5ème arrondissement de la commune de Porto-Novo-Bénin.," 2005.

[19] W. O. K. Van Heerden, J., Ehlers, M. M., Vivier, J. C., & Grabow, "Risk assessment of adenoviruses detected in treated drinking water and recreational water.," *J. Appl. Microbiol.*, vol. 99, no. 04, pp. 926-933., 2005.

[20] S. M. I. Hoteyi, C. C. Gnimadi, G. V Adjadji, A. M. Igue, and G. A. Mensah, "Alimentation de rue des populations: une santé en péril à Cotonou au Sud-Bénin?," *Bull. la Rech. Agron. du Bénin*, pp. 21–34, 2014.

[21] M. AYAD, Wissem et KAHOUL, "Assessment of physico-chemical and bacteriological quality of Well water in the region of El-Harrouch (NE-Algeria)," *J. Mater. Environ. Sci.*, vol. 7, pp. 1288–1297, 2016.

[22] T. B. Mathers C Ma Fat D., "The global burden of disease 2004," *Updat. World Heal. Organ.*, p. 146, 2004.

[23] A. Fakih lanjri, J. Brigui, A. El Cadi, M. Khaddor, and F. Salmoune, "Caractérisation physico-chimique et bactériologique des eaux souterraines de Tanger," *J. Mater. Environ. Sci.*, vol. 5, pp. 2230–2235, 2014.