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Journal of Water Science

ISSN 3068-3882

Research Article

Assessment Of The Physical, Chemical And Bacteriological Properties Of Bottled Water In Six (06) Regions Of Dakar.

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Abstract

The objective of this study was to analyse the impact of bottled water sold in the Dakar region on the health of the population. Sampling was carried out in six (06) areas, namely Grand-Mbao, Keur Massar, Rufisque, Poste Thiaroye, Colobane and Fann. The samples were analysed for physicochemical parameters such as pH, electrical conductivity, total dissolved solids (TDS), nitrites, total alkalinity (TA) and microbiological parameters such as total aerobic mesophilic flora (TAMF) and total coliforms. A statistical analysis was also performed using the ascending hierarchical classification (AHC) methodology to determine the levels of similarity between the different water samples. The results showed that samples 3, 4, 5 and 6 had a slightly alkaline pH between 8.03 and 8.28, exceeding the standards set by the WHO. However, dissolved solids, conductivity, nitrites, TAC and DT were compliant for all samples. Microbiological analysis revealed that sample 2 was contaminated with E. coli at a concentration of 7 CFU/mL, and samples 2 and 4 had an uncountable microbial population exceeding 300 colony-forming units (CFU).

Keywords: Packaged water, quality control, ascending hierarchical classification.

INTRODUCTION

Access to drinking water is essential for the environmental and socio-economic development of a population. This issue, which is of great concern to the international community, is the subject of the sixth sustainable development goal (Reidhead, 2017). Drinking water should comply with the drinking water quality guidelines set by the WHO. These guidelines are reasonable requirements that apply to safe practices designed to protect public health (WHO, 2012). These guidelines form the basis for national standards that take into account the environmental, social, economic and cultural context of each country. Monitoring the quality of drinking water in accordance with these standards ensures its integrity. Furthermore, every year, 1.8 million people, 90% of whom are children under the age of five, most of whom live in developing countries, die from diarrhoeal diseases. Eighty-eight per cent of diarrhoeal diseases are attributable to poor water quality, inadequate sanitation and poor hygiene (WHO, 2004). Globally, nearly 90% of diarrhoeal diseases are attributable to poor drinking water quality and inadequate wastewater sanitation.Water has become a strategic global issue today, and its management must be integrated into a sustainable development policy. Water intended for human consumption must meet a number of organoleptic, physicochemical and microbiological criteria. However, Dakar has a dry tropical climate with an average annual daytime temperature generally exceeding 25°C, meaning that people need to drink regularly in the sun. To meet this need, they often use water bags sold on the street by street vendors. Indeed, the trade in water bags is a very lucrative business in the capital. However, this profitability attracts players who seem to relegate hygiene standards to the background. This is why many private companies have started distributing packaged drinking water in bags under different brands (Dieng et al., 2021) and the Senegalese government has no control over this sector. Yet water should be the most heavily regulated foodstuff. Thus, the consumption of water in bags

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Received: 03-Feb-2026, Manuscript No. JOWS - 5404 **; Editor Assigned:** 04-Feb-2026 **; Reviewed:** 25-Feb-2026, QC No. JOWS - 5404 **; Published:** 14-Mar-2026.
DOI: 10.52338/jows.2026.5404.
Citation: Kalidou BA. Assessment Of The Physical, Chemical And Bacteriological Properties Of Bottled Water In Six (06) Regions Of Dakar. Journal of Water Science. 2026 March; 16(1). doi: 10.52338/jows.2026.5404.

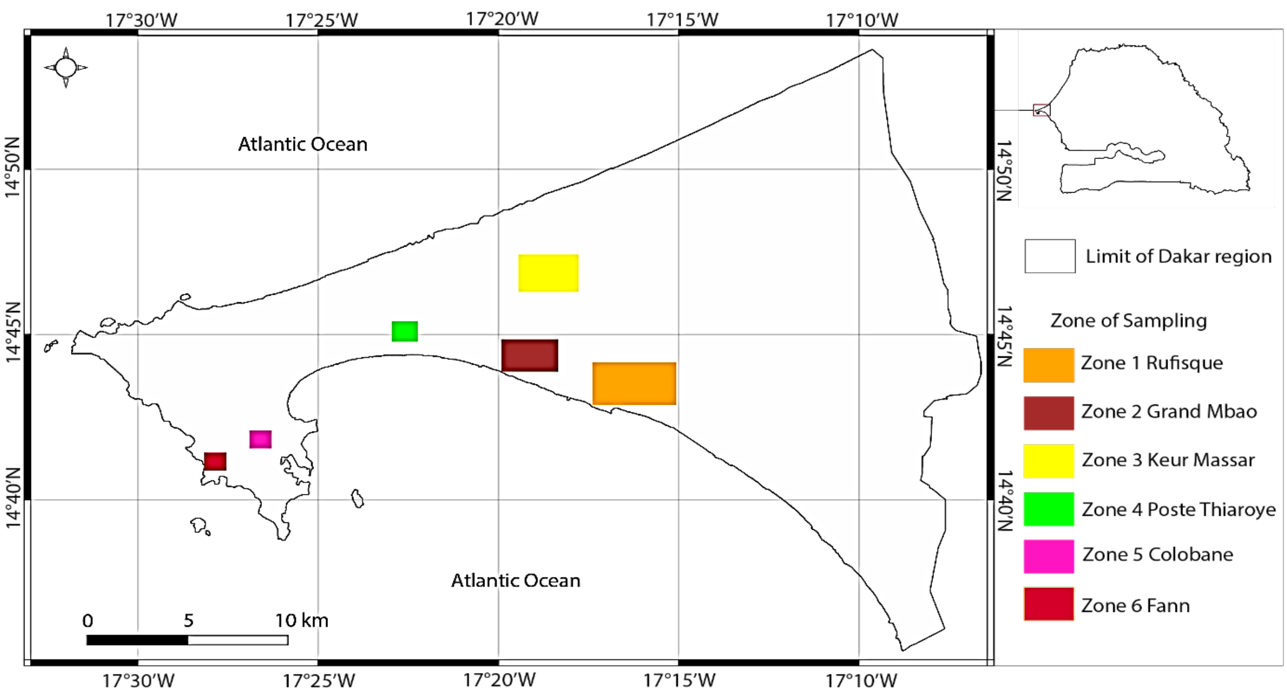
is one of the major challenges that the sanitation, hygiene and water sectors must address in order to eradicate and prevent the risk of waterborne diseases in all regions of Senegal. The objective of this study is to determine the physical, chemical and microbiological characteristics of bottled water sampled in six (06) cities in the Dakar region in order to prevent the population of Dakar from being exposed to waterborne diseases.

MATERIALS AND METHODS

Description of the study area

Dakar is the capital of Senegal and is one of the country's 14 administrative regions. It is the smallest in terms of area, covering 550 km2, or 0.28% of the country. However, it is home to the largest population in Senegal. In 2020, there were 6,973 inhabitants per km², and around 7,200 in 2021. It is located between 17° 10 and 17° 32 west longitude and 14° 53 and 14° 35 north latitude. It is bordered by the Thiès region to the east and by the Atlantic Ocean to the north, west and south. We focused on this region because of its geographical location, which offers a pleasant climate, in addition to its varied economic, political and cultural activities (ANSD, 2023). **Fig. 1** shows the different sampling locations.

Figure 1. The different water sampling areas in bags.



Sampling

The samples analysed were bags of water purchased from shops and street vendors. The sampling points were : Keur Massar, Rufisque, Poste Thiaroye, Colobane and Fann. Sixty (60) samples of water packaged in 300 mL bags were collected at random from five (5) selected markets in Dakar. Six (06) brands of water bags were identified. For this purpose, the different water bags were carefully labelled and coded as follows : Ech 1 (sample 1), Ech 2 (sample 2), Ech 3 (sample 3), Ech 4 (sample 4), Ech 5 (sample 5), and Ech6 (sample 6). After sampling, they were placed directly into a cooler equipped with dry ice before being transported to the Electrochemistry and Membrane Processes Laboratory for physical and chemical analysis and then to the Microbiological Laboratory of the High Polytechnic of Dakar for microbiological analysis.

Measurement of physico-chemical parameters

Physical and chemical parameters such as pH, conductivity and TDS were measured using a FI24-2 multifunctional spectrophotometer equipped with several probes at a temperature of 25°C.

- **Simple alkalinity (TA)**

To determine the alkalinity, 100 mL of each water sample in a bag was placed in a conical flask. One to two drops of phenolphthalein were then added. A pink colour should appear. If this does not happen, the AT is zero. The acid was then slowly poured into the flask using a burette, stirring constantly, until the solution was completely discoloured (Alary & Belles, 2016).

- **Total alkalinity (TAC)**

To determine the total alkalinity (TAC), the water samples used to measure the TA in the absence of pink colouration were used by injecting 2 drops of bromocresol green and methyl red solution. The solution is titrated again with the same acid until the blue-green colour disappears and a pink colour appears. The measurement must be carried out quickly to reduce CO2 losses, which could lead to an increase in the pH of the turning point (Alary & Belles, 2016).

o Total hardness (TH) or hydrotimetric titre (HT)

The TH was determined by placing 50 mL of water from the various sachets to be analysed in a 250 mL conical flask, then adding 4 mL of buffer solution and three drops of eriochrome black T solution. The solution turns dark red or purple, and the pH should be 10. The solution was stirred, then EDTA solution was added quickly at first and then drop by drop when the solution began to turn blue. Towards the end, check that the colour no longer changes by adding an additional drop of EDTA. The total calcium and magnesium concentration, expressed in milliequivalents per litre, is given by equation 1 (Alary & Belles, 2016).

$$\mathrm{DT} = * \frac{\mathrm{C} * \mathrm{V1}}{\mathrm{V2}}$$

Where :
C1 : Concentration in milliequivalents per litre of the EDTA solution.
V1 : Volume in mL of the EDTA solution.
V2 : Sample volume.

o Nitrites (NO2-)

To determine the concentration of nitrites in water samples, the quantities given in **Table 1** are placed in 50 mL vials. A reading is then taken with a spectrophotometer at a wavelength of 543 nm in order to construct the calibration curve. For a 50 mL sample, the curve directly gives the nitrous nitrogen (NO_2) content, expressed in milligrams per litre of water (Alary & Belles, 2016).

Table 1. Preparation of daughter solutions for calibration.

Vial numbers	T	I	II	III	IV	V
1 mg/L (mL) standard solution	0	1	2.5	5	7.5	10
Deionised water	50	49	47,5	45	42,5	40
Correspondence in milligrams per litre of nitrous nitrogen (NO_2)	0	0.02	0.05	0.1	0.15	0.20
Diazotisation reagent (mL)	1	1	1	1	1	1

Analysis of microbiological parameters

With regard to the assessment of microbiological parameters, the analyses performed were based on the identification and enumeration of microorganisms in the samples to be analysed (ISO 5667-3, 2004; ISO 19458, 2006).

Preparation of culture media

A mass of 23 g is dissolved in 1 litre of purified water. The medium is brought to the boil with constant stirring for at least 1 minute. The liquid is divided into bottles and then autoclaved at 121°C for 15 minutes. The medium is liquefied at 100°C in a water bath. The mixture is stirred and allowed to cool to 45-47°C. The medium is then immediately distributed into Petri dishes. However, VRBL was prepared using a ready-to-use VRBL powder (Merck). The pH was adjusted to 7.4 ± 0.1. The medium was boiled for less than 2 minutes until completely dissolved, then cooled and stored at 47 ± 2°C for less than 3 hours before being poured into plates. The liquid was divided into 15 mL and 50 mL aliquots and stored in a refrigerator at 4°C (RODIER et al., 2022).

Detection of bacteria

A cascade dilution is performed to better calculate the load. Buffered water is used as a diluent. Dilutions of 10-1 to 10-6 are obtained, but only dilutions 10-2, 10-4 and 10-6 are used. 1 mL of each dilution is placed in a Petri dish (two Petri dishes are seeded per dilution), then approximately 15 mL of the medium is poured in. We will need 96 Petri dishes for the 6 samples. The Petri dishes will then be incubated in the oven at appropriate temperatures. For PCA, the results will be observed at 48 hours and then confirmed at 72 hours, and for VRBL, an observation will be made at 24 hours and then confirmed at 48 hours.

Statistical analysis

Principal component analysis (PCA) was performed on the various physicochemical parameters of the six (06) samples. This analysis highlights the similarities and differences between individuals (water samples in bags) and the correlations between variables (physicochemical parameters). In order to better classify individuals into classes, this analysis was supplemented by an ascending hierarchical classification.

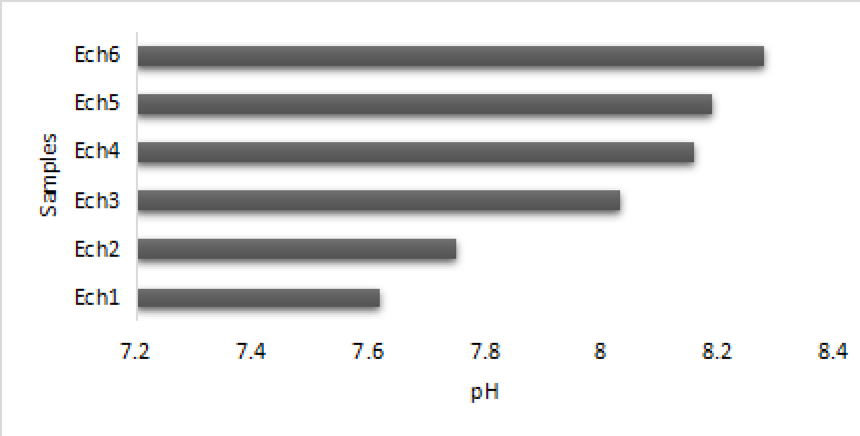
RESULTS AND DISCUSSION

Physicochemical characteristics of bottled water

pH variation

The pH is used to determine whether water is acidic or alkaline. It influences physicochemical balances, particularly the calcium-carbonate balance. Its variation is linked to that of salinity, temperature and CO2 concentration (Abbou, 2014). It is a useful parameter because most biological activities only take place within a narrow range. Consequently, any variation in pH beyond an acceptable limit could be fatal to a particular organism (Trivede, 2010). The pH values obtained vary between 7.62 and 8.28. Looking at **Fig. 2**, samples 3, 4, 5 and 6 have a slightly alkaline pH that exceeds the standards set by the WHO, which stipulates that for drinking water to be properly disinfectable, it must have a pH below 8 (Rodier, 2009) . These pH values above 8 can be explained by the presence of carbonate ions (Gnazou et al., 2015).

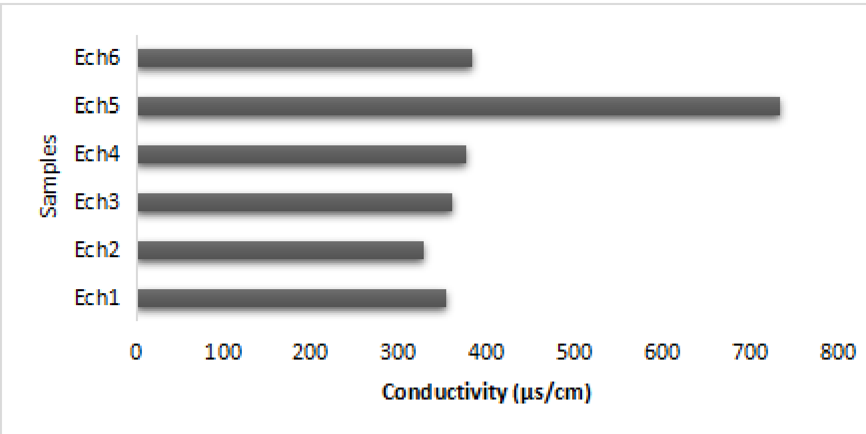
Figure 2. Variation in pH according to the different samples.



Variation in conductivity

Electrical conductivity is a parameter that assesses the ability of an aqueous solution to conduct electrical current. It is induced by the presence of mobile ions in an electric field, and this mobility depends on the nature of the dissolved ions and their concentration (Ayad, 2016). It can be used to determine the total content of mineral ions present in water. The presence of dissolved solids such as calcium, chloride and magnesium in water samples conducts electrical current (Rahmanian, 2015). For these samples, the conductivity varies between 328.779 and 732.99 µs/cm, which indicates an average mineralisation of these waters (Aristide & Ernest, 2020). According to **Fig. 3**, sample 5 has the highest conductivity, but all these conductivity values are below the WHO guideline maximum limit of 1500 µs/cm. Similar results were obtained for water samples in Ethiopia by (Yasin, 2015).

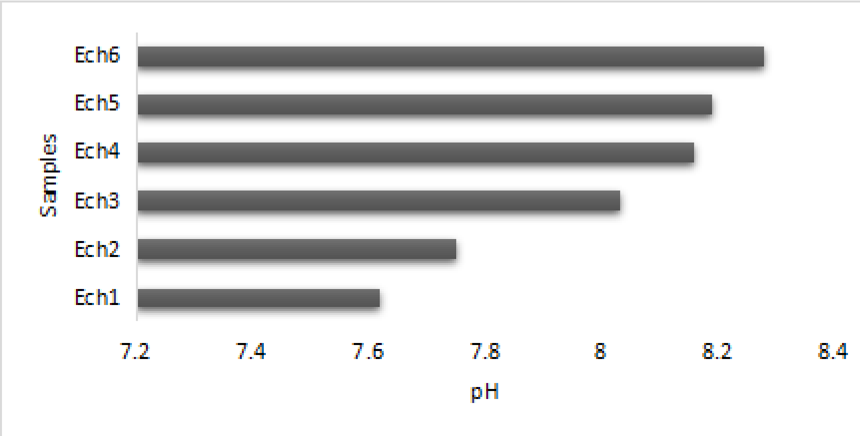
Figure 3. Variation in pH according to the different samples.



Variation in total hardness

The total hardness of the samples fluctuates between 15.93 and 19.245°F. These values are within the range of moderately hard water. However, according to **Fig. 4**, sample 5 has the highest DT value but does not exceed the maximum tolerated value of 1000mg/L (WHO, 1993). These slightly elevated values can be explained by the dissolution of Ca^{2+} and Mg^{2+} ions (Shyamala, 2009) (Patil, 2012) and result mainly from the infiltration of surface water through limestone and dolomite rock formations. This dissolution is increased by the presence of carbon dioxide in the water from the atmosphere and surface soil layers. Hardness has undesirable properties such as the formation of hard deposits in the network's pipes (scaling) and hinders washing operations (Ould Cheikh et al., 2012).

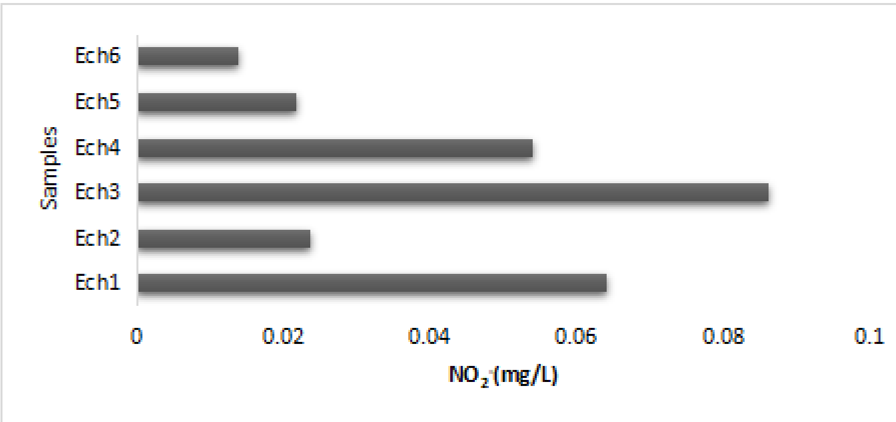
Figure 4. Variation in total hardness according to the different samples



Variation in nitrite content

These samples are characterised by their nitrite content. Nitrites originate either from incomplete oxidation of ammonia or from the reduction of nitrates under the influence of the denitrifying action of bacteria (denitrification). The standard set by the WHO is 0.1 mg/L. For levels above this standard, consumption of this drinking water can cause enormous public health problems. The nitrite concentrations in the different samples range from 0.014 to 0.084 mg/L. However, the analysis in **Fig. 5** shows that sample 3 has a nitrite content of 0.084 mg/L, which is higher than the other samples. This is lower than the concentration obtained by Tchoumou Martin et al., which is 0.17 mg/L for MM1 well water (RODIER et al., 2022), and does not exceed the maximum permissible concentration recommended by the WHO. Consequently, these samples comply with the standards laid down (WHO, 2022).

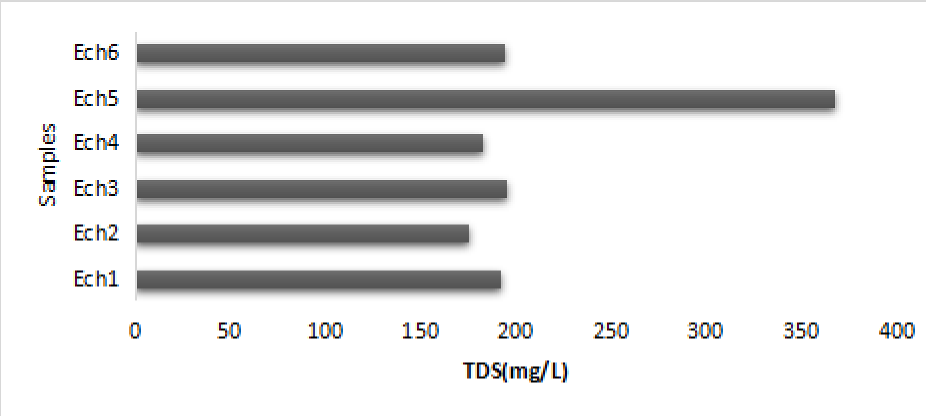
Figure 5. Variation in nitrite content according to the different samples.



Variation in dissolved solids content

Total dissolved solids (TDS), including carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions and other ions, determine the general nature of water quality (Olajire, 2001). They affect the taste of drinking water if they are found in concentrations above the WHO recommended value. The TDS values obtained for the different water samples vary between 175.13 and 367.21 mg/L. However, sample 5 has the highest TDS content according to **Fig. 6**, but this is below the maximum limit allowed by the WHO, which is 1,000 mg/L (WHO, 1996).

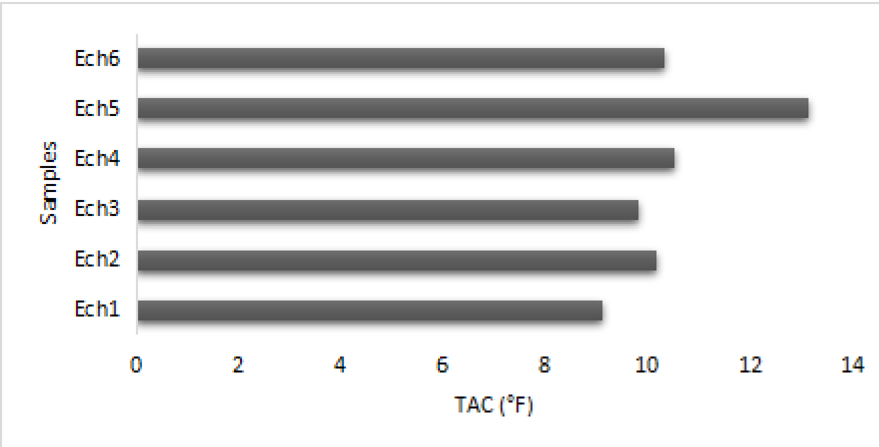
Figure 6. Variation in total dissolved solids content according to the different samples.



Variation in the TAC of samples

The TAC measures the concentration of carbonate and bicarbonate ions present in water. This TAC is of paramount importance for pH balance. A pH that is constantly out of balance may be due to a lack of TAC. The concentration should be between 80 and 120 ppm. If this level drops, the pH will continue to fall. The values obtained for the different samples are between 9.12 and 10.31 °f, which are higher than the 8°f suggested by standard NF EN ISO 9963-1. According to **Fig. 7**, sample 5 has the highest TAC value, indicating the presence of high levels of carbonate and bicarbonate ions in the water. These values are higher than those found by (Seki et al., 2024).

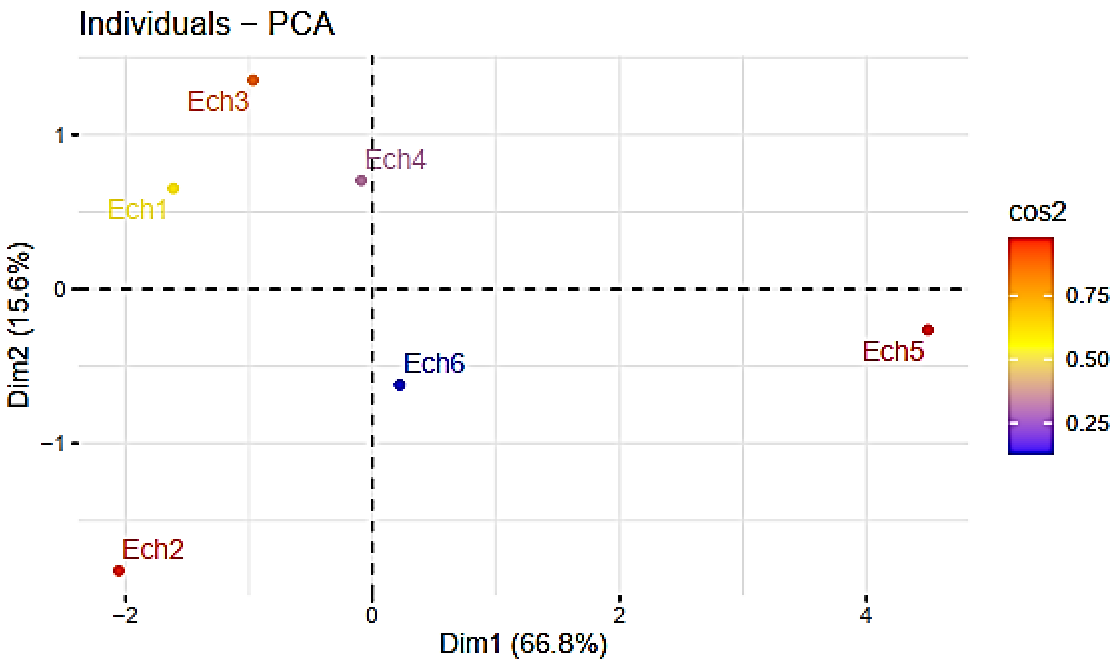
Figure 7. Variation in TAC according to different samples.



PRINCIPAL COMPONENT ANALYSIS

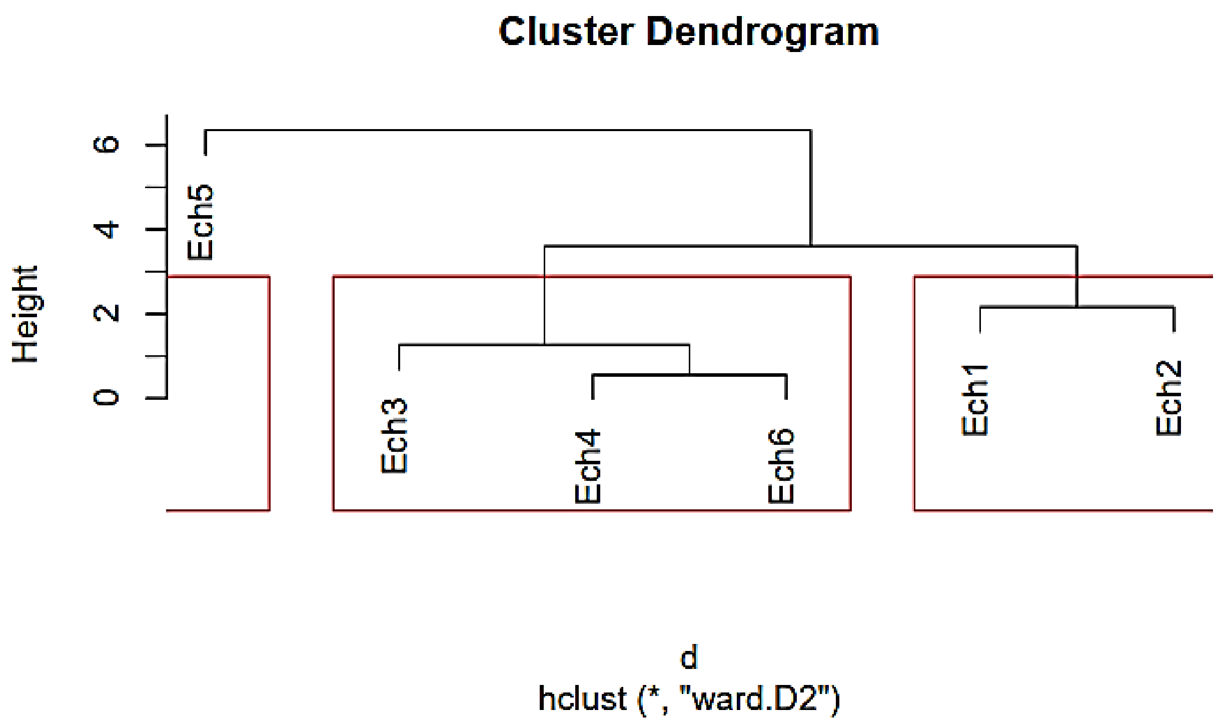
To better assess the quality of bottled water, the data obtained from the physicochemical characterisation are processed using principal component analysis (PCA). This also made it possible to calculate the eigenvalues, the variances expressed for each factor and their cumulative total (Table 2). The analysis on the Dim1-Dim2 factor plane highlighted the general trends. Dimension 1 (Dim 1) has the highest variance expressed at 66.82%, followed by dimension 2 (Dim 2) with 15.6% of the variance expressed. The cumulative variance expressed is 82.42% for both dimensions. These factorial axes selected for this statistical analysis are assumed to be representative of the variance of all observations (**Fig. 8**).

Figure 8. Projection of water samples in bags on the Dim1-Dim2 factorial plane.



In order to classify the water samples into different groups, an Ascending Hierarchical Classification (AHC) was performed using the k-means clustering method, which allowed three groups of individuals to be observed in the dendrogram shown in **Fig. 9**. The overall analysis allows us to define a typology dominated by the individualisation of the three groups. This spatial organisation reveals the exact position of the areas in relation to their location. The first group, group 1, consists of samples 3, 4 and 6 with similar properties and composition, less strongly linked to mineralisation variables such as TDS and conductivity but with higher nitrite contents. Group 2, formed by samples 1 and 2, reflects similar physicochemical properties but is less mineralised than group 1. Sample 5, which is isolated, is strongly associated with mineralisation variables, particularly TDS, conductivity and total hardness, which show that it is very rich in minerals.

Figure 9. Ascending hierarchical classification of water samples in bags according to the variables analysed.



MICROBIOLOGICAL CHARACTERISTICS OF WATER IN POUCHES

Total aerobic mesophilic flora (TAMF)

Analysis of the total mesophilic flora using PCA agar as a culture medium enabled certain microbial populations to be counted and the different values are grouped together in **Table 2**.

Table 2. FMAT of water samples.

	SM		10-2		10-4		10-6	
Ech 1	0	0	0	0	0	0	0	0
Ech 2	ND	ND	293	296	3	3	0	0
Ech 3	0	0	0	0	0	0	0	0
Ech 4	ND	ND	5	6	0	0	0	0
Ech 5	4	3	0	0	0	0	0	0
Ech 6	29	45	1	0	0	0	0	0

Samples 1 and 3 show no bacterial population. Samples 5 and 6 show bacterial populations, but within acceptable limits. However, samples 2 and 4 have an uncountable microbial population, it exceeds 300 colony-forming units (CFU). From a microbiological point of view, these drinking waters are contaminated by total aerobic mesophilic flora (TAMF). Similar results have been reported by Tchoumou Martin et al. (Martin & Conferences, 2023). In fact, the total aerobic mesophilic flora count aims to estimate the density of the general bacterial population present in drinking water, most of the germs that make up this flora are not pathogenic. However, some species can be pathogenic, opportunistic and cause infections in people with weakened immune systems. FAMT is of little use in detecting faecal contamination, but it does provide an estimate of the water's safety.

Coliforms

Coliform analysis using VRBL agar as a culture medium enabled certain microbial populations to be counted, and the various values are grouped together in **Table 2**.

The coliform concentration is zero in all samples except sample 2, which reaches a concentration of 7 CFU/mL. This is a high number of colonies compared to the WHO standard, which sets it at 1 CFU/10 mL. Coliform bacteria are a primary bacterial indicator of faecal contamination in water (Parihar, 2012) (Mohan, 2007). Therefore, testing for total coliform bacteria and Escherichia coli (E. coli) provides an indication of the hygienic status of drinking water and is a major tool in assessing the health risk posed by pathogens present in water (Lukubye, 2017). Consequently, the microbial load can also be attributed to underground leaching from pit latrines and leaching of faecal matter from open defecation into water sources during heavy rainfall. Pit latrines are sources of bacteria in groundwater,

Table 3. Coliform concentrations in samples.

	SM		10-2		10-4		10-6	
Ech 1	0	0	0	0	0	0	0	0
Ech 2	11	3	0	0	0	0	0	0
Ech 3	0	0	0	0	0	0	0	0
Ech 4	0	0	0	0	0	0	0	0
Ech 5	0	0	0	0	0	0	0	0
Ech 6	0	0	0	0	0	0	0	0

and high microbial loads in drinking water can be caused by underground leaching from pit latrines (Bloodless, 2006) (Haruna, 2005). Coliform bacteria such as E. coli are present in large numbers in the intestinal flora of humans and animals, where they are generally harmless. However, in other parts of the body, E. coli can cause serious diseases such as urinary tract infections, bacteraemia and meningitis (WHO, 2017).

CONCLUSION

The assessment of the physical, chemical and bacteriological quality of water in bags in six areas of the Dakar region showed that samples 1 and 2 comply with the physical and chemical values set by the WHO for drinking water, except for samples 3, 4, 5 and 6, which have a slightly alkaline pH between 8.03 and 8.10. Chemical values set by the WHO for drinking water, except for samples 3, 4, 5 and 6, which have a slightly alkaline pH between 8.03 and 8.28. However, from a bacteriological point of view, sample 2 was contaminated with E. coli at a concentration of 7 CFU/mL, and samples 2 and 4 had an uncountable microbial population. This high presence of germs in drinking water may be caused by the discharge of untreated domestic wastewater, underground leaching from pit latrines and the spreading of manure. It is therefore urgent to alert the population to the consumption of water in bags, which can cause waterborne diseases. The health authorities are being called upon to address this situation and must monitor the sale of bottled water.

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