Scientific Research Publishing

Journal of Water Resource and Protection, 2026, 18(1), 18-34
https://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Assessment of Physico-Chemical Quality of Three Water Varieties Consumed in Dakar

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How to cite this paper: Traoré, B., Manga, M. and Ly, E.B. (2026) Assessment of Physico-Chemical Quality of Three Water Varieties Consumed in Dakar. *Journal of Water Resource and Protection*, **18**, 18-34.
https://doi.org/10.4236/jwarp.2026.181002

Received: December 1, 2025
Accepted: January 18, 2026
Published: January 21, 2026

Abstract

Water is a vital resource, and its quality must be regularly monitored to safeguard public health. In Senegal, packaged and tap water are widely consumed, yet their physicochemical characteristics vary and may pose health risks. This comparative study was conducted on 12 water samples collected in the Dakar region, grouped into three categories: bottled water, sachet water, and tap water; 4 samples for each. Physicochemical analyses were performed in accordance with WHO guidelines and the Senegalese standard NS 05-033. The parameters examined included pH, conductivity, hardness, alkalinity, chlorides, and total dissolved solids. Results indicate that bottled water exhibits optimal quality, with a neutral to slightly basic pH and low conductivity (<400 µS/cm). Sachet water shows similar mineralization and hardness (6˚F - 7˚F) to tap water but presents a potential microbiological risk. Principal Component Analysis (PCA) reveals a strong similarity between sachet water and tap water, and also *Kirene* is unique and stands out with its extreme dry residue. This study highlights the importance of regular monitoring and consumer awareness.

Keywords

Drinking Water, Manufactured Water, Chemical Parameters, Quality

1. Introduction

Water is a vital natural resource, essential for the survival of all living beings, from animals to plants. It is one of the fundamental elements of life, involved in numerous biological, chemical, and ecological processes. In 2010, the United Nations General Assembly explicitly recognized access to drinking water as a fundamental human right. This declaration marked a turning point in considering access to water as an issue of social justice and public health. Thus, every individual must be able to have sufficient, continuous, safe, acceptable, and affordable access to water to meet their personal and domestic needs, whether for drinking, washing, or cooking. According to the World Health Organization (WHO), approximately 1.1 billion people worldwide still lack access to drinking water. In addition, 140 million people suffer from consuming or being exposed to unsafe water [1] [2]. This water access deficit represents a major challenge for public health and development [3]. Staying healthy often means having good quality and hygiene of life, and thus having good water quality is an important, even essential, part of this quality of life [1] [2] [4]. Despite this recognition, the situation remains concerning, particularly in developing countries due to a sanitation system and lack of basic infrastructure to prevent the presence of chemical or biological pollutants. Senegal, like many developing countries, faces major challenges in access to drinking water and sanitation. Although progress has been made in recent years, disparities remain between regions. In major cities like Dakar, access to drinking water is relatively well ensured through a public distribution network. However, in rural and peri-urban areas, many residents are forced to rely on unimproved water sources, such as wells, boreholes, or natural water sources—often polluted—requiring treatment before consumption.

Water covers nearly 70% of the Earth's surface, an impressive percentage that highlights its central role in global ecosystems. However, the vast majority of this water is seawater, representing 97.5% of the planet's total water reserves. Only a small portion, 2.5%, is freshwater, essential for human, animal, and plant life. Although freshwater is limited compared to seawater, it is even more striking to note that most of this freshwater is not easily accessible. Indeed, according to WHO estimates and various reports and studies, 68.7% of freshwater is found in polar ice caps and glaciers, making it difficult to exploit. Additionally, groundwater, which requires significant resources and advanced infrastructure to mobilize, accounts for about 30.1% of freshwater. Surface freshwater represents only 1.2%, not always potable and in competition with other sectors such as agriculture or industry. **Table 1** provides an overview of access to this precious liquid, and the observed inequalities worldwide are directly linked to the sanitary disaster of gastroenteric diseases noted in Africa. It should also be noted that there is a pronounced disparity in Africa (Egypt > 1000 and Niger < 300) and in Asia (India >1100 and Yemen <200). Moreover, in Africa and Asia, nearly 90% is allocated to agriculture, whereas in Europe and North America, over 50% is used for industry.

Table 1. Average annual water consumption per inhabitant [7].

	North America	Europe	Africa	Asia	Latin America	Oceania
Water consumption (m^3/person/year)	1600 - 2200	1300 - 1800	500 - 800	900 - 1400	600 - 900	1500 - 2000

All these reasons call for innovative and easily implementable solutions for communities. However, obtaining high-quality water often depends on physical and chemical processes that are frequently unavailable in underdeveloped countries like Senegal [2] [5]-[7]. Moreover, these underdeveloped countries face severe pollution problems due to development needs, rapid urbanization, population growth, and a lack of education.

Population growth and urbanization are maintaining considerable pressure on available water resources. Public authorities are implementing several strategies to improve access to drinking water, such as rehabilitating water supply infrastructure and developing new sources, like dams and boreholes. The Dakar region (7.750 hab/km^2), located above the Maestrichtien aquifer, could be at an advantage, but these groundwater resources cannot be used, because the water table is contaminated with nitrates across almost the entire *The Niayes* area where the boreholes are located. As a result, the water supply comes from distant sources like *Lake Guiers*, which is more than 250 km away and provides almost all the water consumed in the region via state-run infrastructure. Furthermore, the effectiveness of these efforts depends on numerous factors, including resource management, facility maintenance, and adaptation to climate change. Faced with all these constraints, people resort to buying manufactured water sold in supermarkets and on the streets of the capital. In this context, the objective of this study is to measure and analyze the quality of drinking water, such as tap, sachet, and bottled water in the Dakar region through an analysis of the physicochemical parameters of the different types of water.

1.1. Raw Water and Drinking Water

Raw water is any water found in the environment that has not been treated and retains all its impurities (minerals, ions, particles, bacteria, or parasites). Raw water originates from rainfall, surface water (lakes and rivers), and groundwater. Generally, unfit for human consumption, raw water is often in constant contact with contaminants. Using raw water for drinking poses major health risks in some countries today [8]-[10]. It can be used in agriculture (irrigation) and as livestock drinking water. It is widely used in industry, such as mixing water for concrete production, wetting unpaved roads to suppress dust, as a medium for mineral extraction, or as a solvent for dyes in the textile and food processing industries [2] [11]-[18]. It also serves as a medium for river and maritime transport, as well as for energy production (dams, currents).

Drinking water is derived from raw water that has undergone chemical, physical, and microbiological treatment. According to the World Health Organization (WHO), drinking water must be of good quality—meaning it must contain no harmful chemical substances or pathogens that could endanger consumers' health. It must always comply with current health regulations [19]-[26].

In many countries, this water is available through municipal or state networks (tap water) or sold in stores as mineral or specialized water, typically of higher quality in terms of nutrients or for specific needs. In Western countries (Western and Northern Europe, North America, Japan, etc.), there is little difference between these waters. However, in developing nations and the Global South—particularly Sub-Saharan Africa and South Asia, significant differences can often be observed between these water sources.

Tap water, also called **running water**, is drinking water distributed to end-users. It travels from the source (boreholes, rivers, etc.) to consumers' taps. Tap water is treated in purification plants and stored in reservoirs before consumption. Its quality is regulated and subject to health inspections in developed countries. In Maghreb countries or the Middle East (Saudi Arabia, Qatar, Egypt), for example, it may come from seawater desalination [27]-[33].

Natural mineral water is a water category governed by specific regulations. Originating exclusively from underground sources—whether extracted by borehole or emerging naturally—it must demonstrate stable chemical composition and be suitable for consumption without requiring disinfection. However, it may undergo treatments to remove certain toxic or undesirable elements, such as hydrogen sulfides. Natural mineral water is a legally defined water category. Mandatorily of subterranean origin (whether captured via borehole or emerging from a spring), it must maintain stable chemical composition and require no disinfection for consumption. It may nevertheless receive treatments aimed at removing certain toxic or undesirable compounds (such as hydrogen sulphide) [14] [25] [34]-[39].

1.2. Water Quality

Water quality parameters are numerous and diverse. For drinking water, the main focus is on:

1) Organoleptic parameters: color, turbidity, smell;

2) Physicochemical parameters: pH, conductivity, hardness (TH), chlorides, total dissolved solids, alkalinity (TA), and complete alkalimetric title (TAC).

Several countries are their own standards for drinking water according to their population needs and health; and Senegal is not the rest with the NS 05-033 established in 1996. The most common and followed standards are provided by the World Health Organisation. The physicochemical standards from WHO and Senegalese state are summarised in **Table 2**.

Table 2. WHO and Senegalese NS 05-033 (1996) recommendations.

Parameters	WHO Guidelines for Drinking Water Quality (GDWQ)	NS 05-033 (1996)
Temperature (˚C)	25	-
pH	6.5 - 8.5	6.5 - 8.5
Conductivity (µs/cm)	1000	2700
TAC (F)	50	30
Hardness (F)	20	30
Chloride (mg/l)	200	-
Dry Residues (mg/l)	1500	1000

2. Materials and Methods

2.1. Materials

This analysis aims to evaluate various physicochemical and microbiological parameters of water to ensure its compliance with current drinking water standards. Sampling was carried out in five zones within the region, specifically in the neighborhoods of *Rufisque (R1), Keur Massar (R2), Dakar Plateau (R3), and Pikine (R4)*. These tap water samples are from the municipal supply. These collection sites provide a diverse overview of the water's journey through the capital city. Samples were also taken from manufactured waters commonly available on the market, which are often perceived as being of higher quality than tap water. Thus, the selection focused on:

1) For bottled products: *Kirene (B1), Casamancaise (B2), Seo (B3), and Sira (B4)*;

2) For sachet waters: *Seral (S1), Naalaaw (S2), Maya (S3), and Dienaba (S4)*.

Kirene, Casamancaise, and Seo waters are underground mineralized waters and come respectively from natural aquifers: the *Diass Tableland* (Dakar), *Boucotte-Ndiembering* (Ziguinchor), and *Ngoudiane* (Thies), whose descriptions are provided in the table below (**Table 3**). Sira is a purified mineral water. Urban waters come from the supply managed by the National Water Company of Senegal (SONES). Sachet waters come from agro-food industries.

Two sampling campaigns were conducted between April and June 2024. Water samples were collected according to the type of water. Tap water samples were taken directly from the source after allowing the water to run for 3 minutes, thereby excluding stagnant portions in the pipes. Manufactured water samples were collected directly from bottles and sachets as purchased from street vendors and neighbourhood shops in Dakar. All samples were immediately stored in appropriate containers and preserved under optimal conditions to prevent any degradation during transport to the laboratory. To avoid any alteration of the physicochemical characteristics of the samples, water analyses were performed within 24 hours of collection to ensure the accuracy and reliability of the results. To accurately assess the quality of drinking water, it is essential to measure several physicochemical and microbiological parameters.

Table 3. Natural mineral waters.

Eau	Aquifer	Depth
Kirene	Sandy-Calcareous	50 m - 120 m
Casamancaise	Sandy-Sandstone	30 m - 80 m
Seo	Fractured and sandy	80 m - 150 m

2.2. Methods

The pH and the measurements were carried out using the *Orion Star A111* device.

The alkalimetric title (TA) and complete alkalimetric title (TAC) were determined on 100 ml water samples. A few drops of phenolphthalein were added and then titrated with a 0.02 N hydrochloric acid (HCl) solution. A first equivalence point was obtained, allowing the evaluation of carbonate (CO_3^{2-}) and hydroxide (OH^-) ions. Bicarbonate ions (HCO_3^-) were then revealed by adding a few drops of methyl orange, followed by titration with the same HCl solution. The volumes of acid used in the two titration steps allow the determination of TA and TAC according to equations (1) and (2) below.

$$TA(\text{mol/L}) = \frac{[\text{HCl}] \times V_{\text{HCl}}(1)}{V_e} \tag{1}$$

$$TAC(\text{mol/L}) = \frac{[\text{HCl}] \times V_{\text{HCl}}(2)}{V_e} \tag{2}$$

where $V_e(\text{ml}) = \text{volume of sample}(20\ \text{ml})$.

The hydrometric title (TH), or water hardness, measured in mol/L and converted into French degrees (˚F), is primarily determined by the concentration of dissolved calcium and magnesium salts in water. It is determined by titration based on a complexation reaction of the water with an EDTA solution. The collected samples are stabilized with a buffer solution at pH 10; a pinch of copper nitrate (NET) is added, turning the solution pink. This solution is then titrated with 0.05 mol/L of Ethylenediaminetetraacetic acid (EDTA) until a purple coloration appears, indicating the presence of calcium and magnesium in the water. The volumes of EDTA used allow the calculation of the hydrometric title of the sample according to equation (3).

$$TH(\text{mol/L}) = \frac{[EDTA] \times V_{EDTA}}{V_e} \tag{3}$$

Chloride ions (Cl^-) in water samples are detected using potassium chromate (K_2CrO_4), then titrated with silver nitrate (0.1 N) until neutralization, according to Mohr's method. Indeed, once all the chloride ions have precipitated, the excess Ag^+ reacts with the chromate ions to form a reddish-brown precipitate of silver chromate (Ag_2CrO_4). Chloride ions react with silver ions to form a white precipitate of silver chloride (AgCl).

$$2\text{Ag}^+ + \text{CrO}_4^{2-} \rightarrow \text{Ag}_2\text{CrO}_4 \tag{4}$$

$$\text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl} \tag{5}$$

The concentration of chloride ions is calculated using Equation (6):

$$\left[\text{Cl}^-\right] = \frac{[\text{AgNO}_3] \times V_{\text{AgNO}_3}}{V_e} \tag{6}$$

Dissolved solids are obtained by evaporating the water sample, followed by calcination in an oven at 120˚C. The mass of dissolved solids in the water sample is determined by the difference in mass before and after evaporation. This value reflects the concentration of non-volatile substances present in the sample.

$$RS = \frac{m_1 - m_2}{V_e} \times 1000 \quad (7)$$

where: m_1 *: mass of the watch glass after evaporation;* m_2 *: mass of the empty watch glass.*

Principal Component Analysis (PCA) is a statistical method that helps simplify complex datasets by reducing the number of variables while preserving essential information. PCA is a highly useful technique for exploring complex datasets, as it allows for the identification of hidden patterns and the visualization of the underlying structure of relationships between different variables. The entire analysis was performed using version 4.5.1 of *RStudio*.

3. Results and Discussion

This study presents the physicochemical properties of water commonly consumed in the Dakar region and applies principal component analysis (PCA) to explore correlations among the collected water quality parameters.

3.1. Physicochemical Properties

The pH, which measures the concentration of hydronium ions (H_3O^+) in water, is a key indicator of its acidity or alkalinity. It can vary depending on several factors, including the geological nature of the terrain through which the water flows, the presence of dissolved minerals, and water treatment processes. In general, the pH of drinking water should fall within a specific range (6.5 to 8.5, WHO) to ensure its potability and safety for human consumption. The pH values of the water samples are presented in Table 4.

Table 4. Global physicochemical characteristics.

	pH	TAC (˚F)	TH (˚F)	Cl^- (mg/l)	Cond (µs/cm)	RS (mg/l)
Kirene	6.78 ± 0.02	13.60 ± 0.30	6.63 ± 0.13	30.18 ± 1.78	373 ± 3	730
Casamancaise	6.52 ± 0.02	5.25 ± 0.65	3.00 ± 0.25	37.28 ± 1.78	214 ± 6	45
Seo	7.30 ± 0.05	6.10 ± 0.20	3.63 ± 0.13	37.28 ± 1.78	268 ± 8	140
Sira	7.01 ± 0.00	1.10 ± 0.20	0.50 ± 0.00	35.50 ± 0.00	38 ± 2	55
Seral	7.52 ± 0.07	5.10 ± 0.60	2.00 ± 0.25	19.53 ± 1.78	100 ± 2	250
Naalaaw	7.95 ± 0.05	14.05 ± 0.15	6.75 ± 0.25	40.83 ± 1.78	431 ± 21	360
Dieneba Daye	8.10 ± 0.04	14.50 ± 0.00	7.38 ± 0.13	51.48 ± 5.32	498 ± 7	175
Maya	7.63 ± 0.13	15.65 ± 0.35	7.25 ± 0.25	44.38 ± 1.78	482 ± 8	510
Rufisque	7.35 ± 0.16	19.15 ± 1.85	6.63 ± 1.38	62.13 ± 5.33	661 ± 95	230
Keur Massar	7.29 ± 0.20	13.58 ± 1.12	7.50 ± 0.00	42.60 ± 3.55	483 ± 5	50
Dakar plateau	7.34 ± 0.00	14.45 ± 0.45	7.38 ± 0.38	49.70 ± 0.00	500 ± 16	230
Pikine	7.37 ± 0.17	14.20 ± 0.50	6.63 ± 0.38	42.60 ± 0.00	480 ± 14	155

3.2. Alkalinity and Buffering Capacity

The average values of total alkalimetric title (TAC), hydrometric title (hardness), and water conductivity measurements are presented in **Figure 1** below. This graph allows for a comparison of the concentration of alkaline ions (bicarbonate HCO_3^-, carbonate CO_3^{2-}, and hydroxide OH^-) in each type of water, providing a precise evaluation of their alkalinity. The results obtained from the analysis of different water sources show a clear difference in the physicochemical characteristics of the studied water types. Specifically, bottled waters are distinguished by particularly low average values, ranging from 1.1˚F to 13.6˚F for bicarbonate content (HCO_3^-). This low HCO_3^- content indicates that these waters are less mineralized with respect to this specific component, which may suggest more advanced filtration or treatment processes to make the water purer and more pleasant for consumption. This type of water is often perceived as softer, with a lighter taste, which can influence consumer preferences. On the other hand, sachet waters and bottled waters, although originating from different sources, show notable similarities in terms of their TAC. Indeed, their relatively low values—particularly for mineral waters—indicate similar buffering capacities, *i.e.*, their ability to neutralize acids. These similarities may result from comparable treatment processes or similar supply sources, which can significantly influence the composition of these waters. In terms of drinking water recommendations, the analyzed waters comply with both WHO and Senegalese standards (NS 05-033), which set TAC thresholds at 50˚F and 30˚F, respectively.

3.3. Water Hardness and Conductivity

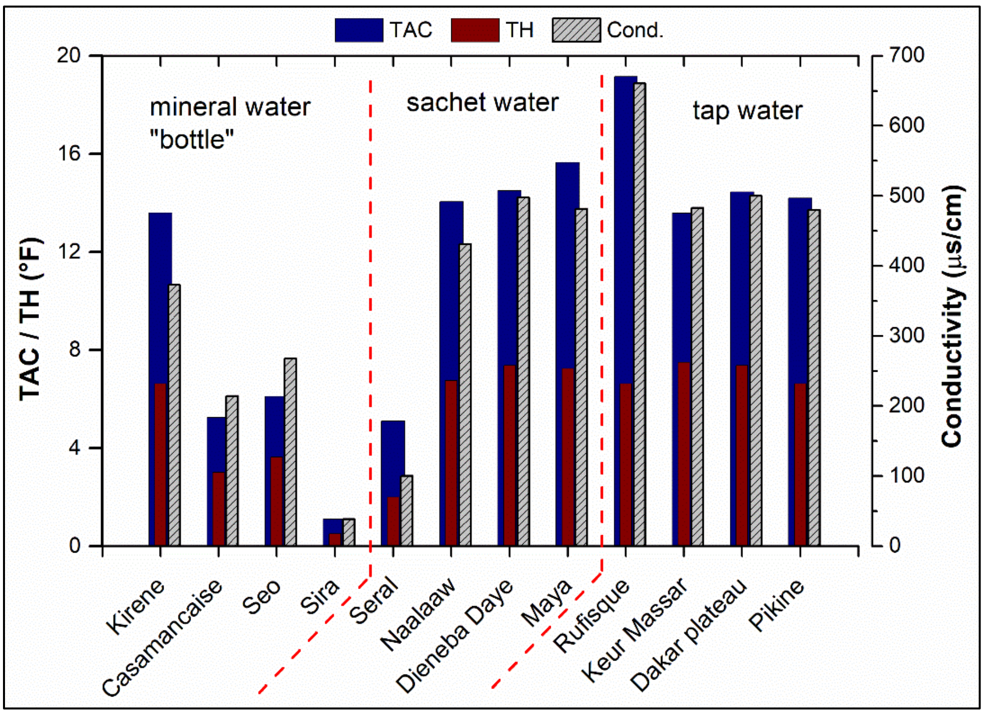

Figure 1. Characteristics of consuming waters in Dakar.

Water hardness reflects the concentration of calcium (Ca^{2+}) and magnesium

(Mg^{2+}) ions in water. Excessive hardness can lead to scale deposits in plumbing systems and household appliances, while very low hardness may indicate insufficient mineral content, which can affect water taste and nutritional value. The analysis revealed that bottled waters exhibit low hydrometric values, ranging from 0.5˚F to 6.7˚F, characteristic of soft and light water. This low mineralization makes them suitable for drinking and often preferred for their lighter taste. In contrast, sachet waters show hardness values between 2˚F and 7.4˚F, similar to those observed in tap water, suggesting a possible link to the same supply source. This observation raises concerns about the origin and treatment of sachet waters, as some may simply be packaged tap water without additional purification, given the lack of strict regulatory oversight. Despite these differences, all measured values comply with WHO and Senegalese standards (NS 05-033), which set upper hardness limits at 30˚F and 20˚F, respectively. The variation in hardness between bottled waters (less mineralized) and other water types is primarily perceptible in taste, a difference that often goes unnoticed by consumers.

Figure 1 illustrates the fluctuating conductivity levels observed among the different types of water analyzed in this study. All samples comply with WHO guidelines (**Table 2**) for drinking water, which recommend conductivity values below 1000 μS/cm. Conductivity serves as an approximate indicator of the overall mineralization of water, as it reflects the presence of dissolved substances such as sulfates, chlorides, and bicarbonates originating from reservoirs and geological formations along the water's path. It is therefore considered an indirect measure of mineral content. The very low conductivity values recorded in this study are typical of waters with minimal dissolved elements. This characteristic makes them particularly suitable for daily consumption, as they pose no risk of excessive mineral intake. Such waters are often perceived as lighter and more palatable, which can influence consumer preference.

The electrical conductivity of water and its hardness are two distinct parameters, but they are indirectly linked through their common dependence on mineralization. Conductivity depends on the concentration and mobility of all dissolved ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+, Cl^-, NO_3^-, HCO_3^-, SO_4^{2-}, CO_3^{2-}) present in the water, making it an overall indicator of total ionic load and the intensity of mineralization. Hardness, on the other hand, only accounts for the fraction of mineralization related to alkaline earth cations, primarily Ca^{2+} and Mg^{2+} ions.

3.4. TAC and Hardness Comparison

Figure 1 shows that in almost all samples, TAC > TH, which indicates balanced water, and the pH values obtained are slightly basic, consistent with the titration results (**Table 4**). Based on the alkalimetric and hydrometric values, three categories of bottled water can be distinguished: *Kirene*; *Casamancaise-Seo*; and *Sira*. Furthermore, the characteristics of Seraal water are quite similar to those of bottled waters. Since bottled waters exhibit the best quality, it can be assumed that Seraal is of higher quality than other waters in its category, suggesting that its source undergoes rigorous and more comprehensive treatment. Sira water, with relatively low titration values compared to other bottled waters, is very low in mineral content and therefore even softer.

3.5. Chloride and Water Treatment

Figure 2 highlights the concentration of chloride ions in the waters consumed in the Dakar region. The chloride levels are relatively significant but remain within the limits set by WHO drinking water standards (<200 mg/L) and, consequently, the Senegalese standard of 300 mg/L. Chlorine is often added by water treatment plants to eliminate bacteria. Sachet waters exhibit characteristics similar to tap water, except for higher chloride concentrations in tap water. This suggests that sachet waters originate from tap water with some chlorine treatment. *Seral* water stands out for its low chloride content, confirming previous conclusions regarding its treatment system. *Kirene*, *Casamancaise*, and *Seo* waters are of underground origin; the chloride ion results for bottled waters likely reflect treatment against bacteria and parasites. The same applies to Sira water, which is urban water treated using filtration techniques.

An excessive concentration of chlorides can cause undesirable effects, particularly on the taste of water, the corrosion of water distribution systems and equipment, as well as on health, especially for individuals suffering from kidney disease or hypertension. However, the values obtained in this study comply with drinking water standards.

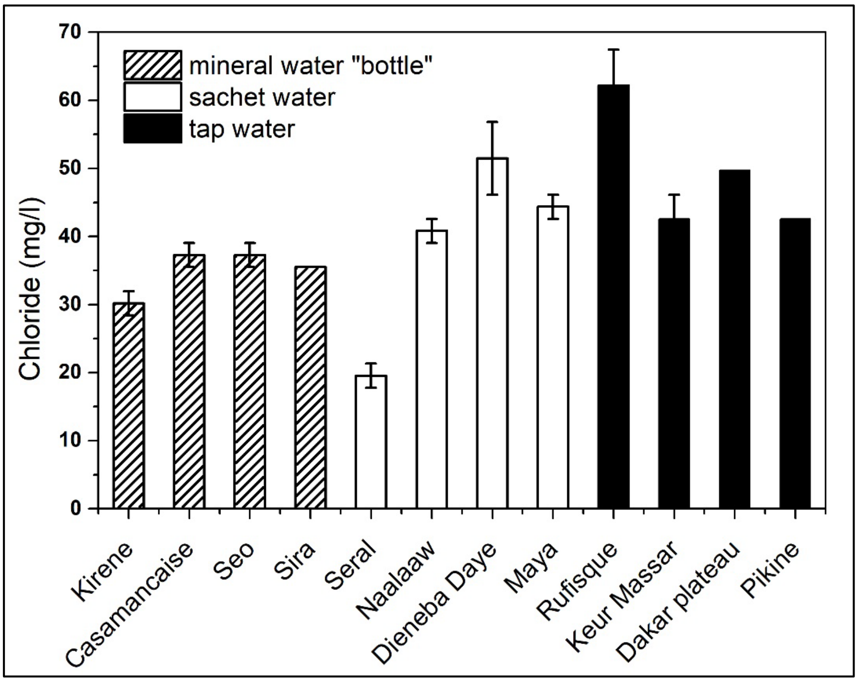

Figure 2. Chloride concentration of consuming waters in Dakar.

3.6. Dry Residue and Mineral Load

The dry residue or total dissolved solids (TDS) contents presented in **Table 1** for the different water samples show a slight difference between the two sampling campaigns. Overall, TDS concentrations range from 45 to 730 mg/L, values that remain well below the limits set by drinking water standards and requirements applied in Senegal. The results of the two campaigns indicate variations in concentration among the different parameters studied, which is entirely normal. This variation can be attributed to several factors, notably the amphoteric nature of water—its ability to act both as an acid and as a base—affecting its capacity to dissolve or precipitate certain components depending on local conditions. Dry residues in water are mainly due to the presence of dissolved inorganic substances such as salts, minerals, and metals, as well as colloids, clays, and organic matter. Although not all of these elements are harmful to human health, they contribute to the mineral load of water and can affect its taste, clarity, and suitability for industrial or domestic processes.

In conclusion, although the variations observed between the two campaigns are normal, it is essential to continue monitoring these concentrations to ensure that the water remains compliant with quality standards and is safe for human consumption.

3.7. Principal Component Analysis

A principal component analysis (PCA) was conducted to investigate two main aspects: (i) the interrelationships among the physicochemical parameters of the water samples, and (ii) the associations between the various water sources considered in the study. PCA, a multivariate statistical technique, was employed to reduce the dimensionality of the dataset while retaining the most significant information. The analysis revealed two principal components that together account for 82.86% of the total variance, thereby providing a robust summary of the underlying data structure (**Figure 3**).

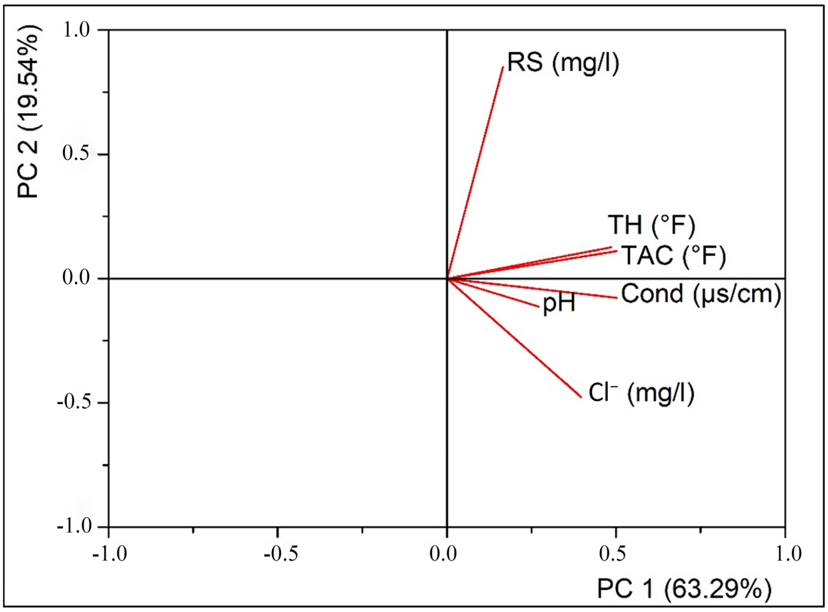

Figure 3. Distribution of studied parameters.

The analysis highlighted the main sources of variation among the measured physicochemical parameters. Through this approach, both similarities and differences between the various water samples were clearly identified. The first two principal components together account for nearly 80% of the total information contained in the dataset, indicating that the majority of the variance can be explained by these two dimensions. This high level of representativeness effectively summarizes the general trends in water quality observed across the samples.

Figure 3 shows positive correlations between TH, TAC, and water conductivity, and opposite variations in chloride content and dry residue. On the other hand, pH is correlated with conductivity but does not significantly impact the study data. TAC, TH, and conductivity values are representative of the study conducted; likewise, chloride and dry residue levels are fairly representative of the study.

The interpretation of the graphs allowed us to conclude that water hardness does not have a direct influence on pH. However, it appears that dissolved substances in water vary according to pH. Indeed, a decrease in pH is often associated with a reduction in bicarbonate (HCO_3^-) concentration. Bicarbonates play an important role in regulating water pH, acting as buffers to maintain stability. A decrease in their concentration can lead to a drop in water pH, making it more acidic. Moreover, the variation in dry residue (RS) in water is generally linked to the concentration of dissolved mineral salts. When the concentration of dissolved salts increases, the amount of dry residue in the water also rises, reflecting the water's mineralization. Moderate alkalinity values observed in some waters are correlated with low hardness levels, which means these waters have a low corrosive character. Moderate alkalinity allows water to maintain a stable pH while reducing the risk of corrosion in installations and pipelines.

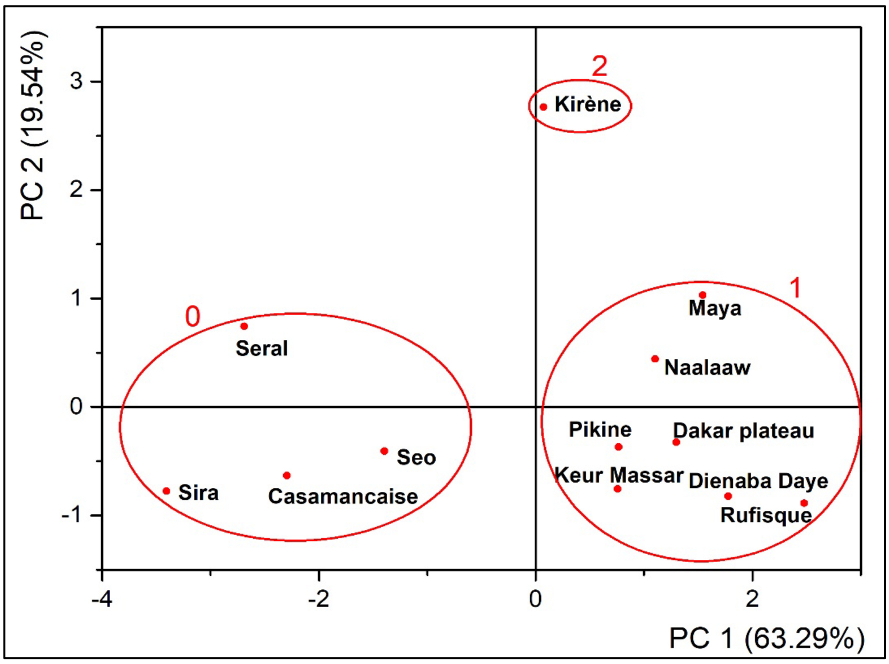

Figure 4. Two-dimensional representation of waters.

The analysis of the graphs allowed us to better understand the interactions between the physicochemical parameters of water, particularly hardness, pH, alkalinity, and dry residue. These parameters are interconnected and influence not only water quality in terms of taste and safety but also its impact on domestic and industrial installations. Continuous monitoring of these parameters is therefore essential to ensure optimal water management, especially in regions where water quality can vary significantly. The results of the factor analysis made it possible to group the different waters analyzed according to their similarities, identifying common patterns and trends among the samples.

The statistical method revealed that samples within each group share very similar physicochemical characteristics, meaning they are strongly correlated. In other words, waters belonging to the same group have similar composition profiles, allowing them to be classified consistently according to specific criteria. Based on the results of the factor analysis, the samples were divided into three (03) distinct groups, each characterized by a set of common properties (**Figure 4**).

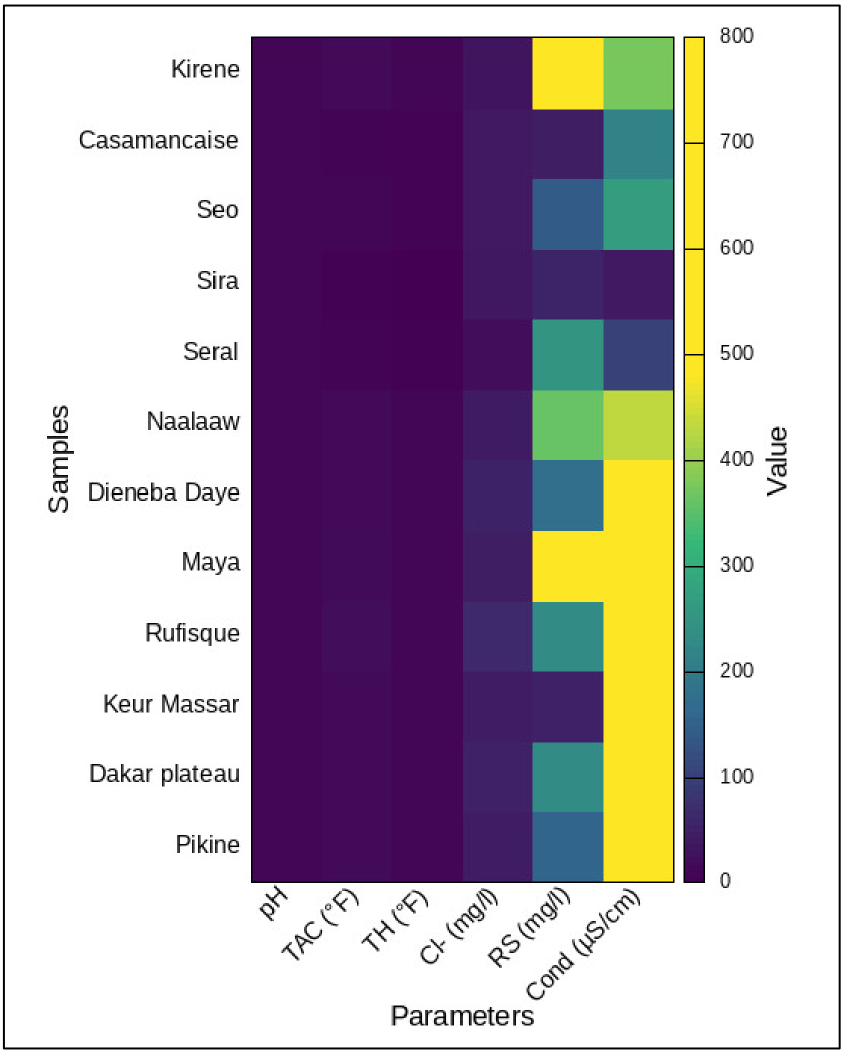

Figure 5. Heatmap of water sample characteristics.

1) Cluster 0: Low Mineralization Waters: This cluster is characterized by very low alkalinity (TAC) and hardness (TH), combined with low conductivity. It includes two bottled waters, *Sira* and *Casamancaise*, *Seo*, as well as the sachet water *Seral*. The inclusion of Seral in this group confirms its similarity to bottled water in terms of physicochemical properties.

2) Cluster 1: Mineralized Waters: Comprising *Rufisque*, *Pikine*, *Maya*, and *Naalaaw*, this cluster represents waters with high TAC and TH values and strong conductivity. These characteristics indicate a significant level of mineralization.

3) Cluster 2: Extremely High Dry Residue: This cluster contains only *Kirene*, which stands out due to its exceptionally high dry residue (RS). *Kirene* is markedly different from all other drinking waters analyzed in Dakar, making it unique in its composition.

The heatmap (**Figure 5**) shows absolute values for each variable across samples. This representation of ACP results offers another view of sample characteristics.

1) *Kirene* stands out with the darkest cell in the RS column (730 mg/l), confirming its extremely high dry residue.

2) *Casamancaise, Seo*, *Sira*, and *Seral* have very light colors across most variables: very low mineralization.

3) *Rufisque*, *Pikine*, *Dakar Plateau*, *Maya*, and *Naalaaw* show darker shades in TAC, TH, and conductivity: highly mineralized waters.

Both visualizations agree on the main patterns.

4. Conclusion

The results of the analyses conducted on the various water samples collected during this study indicate that the quality of drinking water in the Dakar region is generally satisfactory. The study revealed notable differences in water quality across bottled, sachet, and tap water samples. Most samples had TAC > TH and a slightly basic pH, indicating balanced water. Bottled waters were categorized into three groups (*Kirene, Casamancaise-Seo, Sira*), with *Seral* showing similar quality. Bottled waters showed low bicarbonate levels (1.1˚F - 13.6˚F), indicating low mineralization due to advanced treatment. Sachet and tap waters had similar TAC values, possibly due to shared sources or treatment methods. The hardness (TH) Bottled waters were soft (0.5˚F - 6.7˚F), while sachet and tap waters ranged from 2˚F - 7.4˚F, suggesting sachet water may originate from municipal sources. Tap water had higher chloride levels than sachet water, implying sachet water may be treated tap water. *Seral* had low chloride, confirming its superior treatment. The Total Dissolved Solids (TDS) ranged from 45 to 730 mg/L, well below regulatory limits. The variations between sampling campaigns were normal and attributed to water's amphoteric nature and environmental factors. All sample characteristics complied with WHO and *Senegal* regulations (**Table 2**).

Acknowledgements

The authors thank the National Laboratory for Analysis and Control of the Senegalese Ministry of Industry and Trade.

Conflicts of Interest

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

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