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# Analysis of minerals in filtered and purified water sold in Senegal

**Sylla Gueye Rokhaya*[1], Diop Cheikh[2], Diouf Louis A.D.[3], Balde Mamadou[1], Diedhiou Adama[1], Ndoye Idrissa[1], Tine Yoro[1], Seck Matar[1], Fall Djibril[1] and Wele Alassane[1]**

*[1]Laboratory of Organic and Therapeutic Chemistry, Faculty of Medicine, Pharmacy and Odontology (F.M.P.O.), Cheikh Anta Diop University (U.C.A.D), Dakar, Sénégal*
*[2]Laboratory of Toxicology and Hydrology, F.M.P.O., U.C.A.D*
*[3]Laboratory of Biophysics and Pharmaceutical Physics, F.M.P.O., U.C.A.D*

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**ABSTRACT**

*Nitrates, chlorides, fluorides and sodium ions were analyzed in filtered and purified water sold in Senegal in small plastic pouches. These pouches are subject to significant consumption by the population. Sodium ions were determined by flame photometry while the other mineral elements were determined by specific electrodes. Of the 6 samples studied, 5 had volumes non-compliant with respect to what was mentioned on the packaging. The analysis of nitrates showed relatively high concentrations, between 50 mg/l and 70 mg/l, for all 6 samples. A maximum of 25 mg/l of nitrates is recommended, by the World Health Organization (WHO), in water intended for consumption. The contents of the samples in fluorides, ranging from 6 mg/l to 11 mg/l, were significantly elevated compared to the standard of WHO in drinking water, which is 1.5 mg/l. The chloride contents of the samples ranged from 40 mg/l to 100 mg/l for all 6 samples, less than the maximum of 250 mg/l of chlorine tolerated by WHO. The sodium content of the studied samples ranged from 26 mg/l to 56 mg/l. For sodium, WHO has not made any recommendation for water intended for consumption, although in Senegal, 200 mg/l is applied.*

**Keywords**: Minerals, Water quality, Senegal

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## INTRODUCTION

In nature, water is not a pure chemical compound. It is an aqueous solution containing various mineral salts or other compounds [1, 5, 7, 10-11, 13, 16-17]. Thus, its composition in terms of these elements determines its potability, and therefore its interest for man [8, 14].

Indeed, water is essential to life. No living being can survive without water on our planet. Thus, WHO launched the slogan "Water for Life" for the decade 2005-2015, in an effort to make this precious resource of good quality and accessible to all.

According to WHO, 20% of the world population has no source of drinking water. Every year millions of people, mostly children, die from diseases associated with lack of safe water, sanitation and hygiene. Every day about 3,900 children die because of dirty water or poor hygiene. Diseases transmitted through water or human waste are the second cause of death among children worldwide, after respiratory diseases [20].

Water's mineral content is also very important, minerals being essential to the enzymatic and hormonal functioning of the body, the structure of bones and teeth, maintaining heartbeat, muscle contraction, neuronal conductivity and acid-base balance. However, for some minerals, relatively high levels can be source of toxicity [3, 8-9, 18].

In Senegal, the consumption of mineral water in bottles [15] and plastic pouches has been experiencing a real boom in recent years. The conditions for preparing and selling these products require significant precautions that are not always respected. In particular, the expiration dates are not always reported or are often illegible.

Therefore, the objective of this study is to perform a quality check on filtered, purified and conditioned water sold in plastic pouches, in Senegal.

The physicochemical characterizations were carried out by electrochemical methods with the use of specific electrodes for the determination of ions in solution. This analysis protocol has the advantage of being simple, inexpensive, and routinely used [2, 4, 12, 19].

## EXPERIMENTAL SECTION

### Sampling

The study was conducted in Dakar (Senegal) from November 2012 to January 2013. The Dakar region covers an area of 550 km², or 0.28% of the national territory. It is the political, economic and cultural capital of Senegal, with 80% of all commercial and cultural enterprises and nearly a quarter of the total population.

The samples comprised filtered and purified water, packaged and sold in plastic pouches. They were collected from randomly selected shops. The samples were manufactured by companies based in Dakar under fancy names like Ganalé, Mariam, Moul, Si belle, Sunu ndox, Téranga.

Samples were collected at the time of the study and exposed to room temperature without special precautions. A water pouch was used for each assay type and opened just before analysis. Table 1 summarizes some miscellaneous sample information.

**Table 1 : Miscellaneous packaging and price information (1 FCFA = 0.0017 US $)**

| **Brand** (company) | **Volume (ml)** | **Expiration date** | **Price (FCFA)** | **Price per liter (US $/l)** |
|---|---|---|---|---|
| **SI BELLE** (Transversale) | 400 | Dec 2013 | 50 | 0.21 |
| **SUNU NDOX** (GIE Jappo Liguey) | 250 | N.A | 25 | 0.17 |
| **MARIAM bint imraan** (GIE Al Istiqaama) | 250 | N.A | 25 | 0.17 |
| **MOUL** | 500 | N.A | 50 | 0.17 |
| **TERANGA** (SIAD) | 250 | 10/03/2013 | 25 | 0.17 |
| **GANALE** (Loum et Freres) | 400 | Not readable | 25 | 0.11 |

### Apparatus and reagents

A CONSORT pH meter was used for the analysis of different ions, with an ORION model 93-07 electrode for nitrate ions, an INGOLD model 15 213 300 electrode (with $AgCl/Ag_2S$ pellets) for chloride ions, an ORION 94-09, 96-09 electrode (with lanthanum fluoride crystals) for fluoride ions, and a reference electrode INGOLD model 373 90 WTE. ISE. S7 (with Ag/AgCl). Finally, the analysis of sodium ions was performed with an ELVI 660 flame photometer.

All reagents used met purity requirements for analysis.

### Methods

Two analytical techniques were used in this study: the electrochemical method by applying specific electrodes for the determination of nitrate, chloride and fluoride ions, and flame photometry for the determination of sodium ions.

### Analysis of ions by electrochemical method

This method consisted of measuring the potential using a system of electrodes and a potentiometer. The potential at the working electrode was measured directly relative to a reference electrode [4, 19]. After this measurement, the concentration of the sample ion was determined using a calibration curve established with known concentrations of the measured ion.

The addition of a TISAB (Total Ionic Strength Adjustment Buffer) buffer solution allowed to increase the ionic strength and maintain the stability of the solution for analysis [4, 19]. Each one of the analysis uses a specific TISAB solution.

**Determination of nitrate ions**
The stock solution was obtained from potassium nitrate. Its concentration in nitrates, 0.885 g/l, yielded daughter solutions of concentrations 0.443 g/l, 0.222 g/l, 0.088 g/l and 0.044g/l.

For the determination of nitrates, the reference electrode was filled with a saturated solution of potassium chloride, and the TISAB solution was an ammonium sulfate of 2M.

**Determination of chloride ions**
The stock solution was composed of sodium chloride at a concentration of 0.76 g/l from which daughter solutions of concentration of 0.38 g/l, 0.19 g/l, 0.076 g/l, and 0.038 g/l were extracted. The determination of chloride ions required as a reference, a potassium nitrate solution of 1M. The TISAB solution was a sodium nitrate of 425 g/l concentration.

**Determination of fluoride ions**
The stock solution was made of sodium fluoride at a concentration of 0.1 g/l, and daughter solutions of concentrations 0.050 g/l, 0.25 g/l, 0.010 g/l and 0.005 g/l were produced.

The filling solution of the reference electrode for the determination of the fluoride ions is a potassium chloride solution at a concentration of 100 g/l. The TISAB solution was made of an equal mixture of trisodium citrate at a concentration of 58.8 g/l and a sodium chloride solution at a concentration of 58.5 g/l. A citric acid solution of concentration 12.5 g/l was used to adjust the solution prepared at a pH of 5.5.

**Joint Protocol for the analysis of nitrate, chlorides, and fluorides ions**
In a 150 ml beaker was introduced 25 ml of the water sample and 0.5 ml of the TISAB solution. The specific electrode is carefully washed with distilled water, dried with filter paper and then introduced into the solution to be analyzed, as well as the reference electrode filled with the saturated solution specific to the ion being analyzed. Reading of the potential was made after 5 min including 2 min of very gentle magnetic stirring followed by 3 min of rest. After each reading, the electrodes were again thoroughly rinsed with distilled water and then dried with filter paper.
This procedure was performed for each solution of the calibration range and for each sample. Each solution was measured three times and the mean and standard deviation of the measurements were calculated.

**Determination of the sodium by flame photometry**
The stock solution was made of sodium chloride with a concentration of 0.5 g/l, and daughter solutions with sodium ion concentrations of 0.25 g/l, 0.025 g/l, 0.010 g/l, and 0.005 g/l were prepared. The flame photometer was calibrated so that the intensity of the current was between 0 mA and 95 mA. The results obtained allowed to plot calibration curves used to determine concentrations of samples to be analyzed.

## RESULTS AND DISCUSSION

The volumes of water pouch samples were measured using measuring cylinders and the results are shown in Table 2:

**Table 2 : Claimed and measured volumes of different samples**

| Sample | Ganalé | Mariam | Moul | Si belle | Téranga | Sunu ndox |
|---|---|---|---|---|---|---|
| Measured volume (ml) | 230 | 370 | 360 | 360 | 260 | 260 |
| Claimed volume (ml) | 250 | 250 | 500 | 400 | 250 | 250 |

**Results of analysis by specific electrodes**
The various concentrations were determined using the equation $Y = A + BX$ given by the calibration curve, where $Y$ is the potential in mV, $A$ is the $Y$ intercept, $B$ is the slope of the line, and $X$ is the logarithm of the concentration of the element to be analyzed.

## Determination of nitrate ions

**Table 3: Concentrations (g/l) of nitrates in calibration solutions**

| Calibration solution | Stock | 1 | 2 | 3 | 4 | Distilled water |
|---|---|---|---|---|---|---|
| Mean Potential (mV) | 68 | 82.87 | 98 | 116.33 | 128.67 | 164.33 |
| Concentration (g/l) | 0.916 | 0.445 | 0.209 | 0.085 | 0.046 | 0.008 |

**Table 4: Concentrations (g/l) of nitrates in samples**

| Sample | Ganalé | Mariam | Moul | Si belle | Sunu ndox | Téranga |
|---|---|---|---|---|---|---|
| Mean Potential (mV) | 128.33 | 123.67 | 124.67 | 120.00 | 124.67 | 123.67 |
| Concentration (g/l) | 0.05 | 0.06 | 0.06 | 0.07 | 0.06 | 0.06 |

## Determination of fluoride ions

**Table 5: Concentrations (g/l) of fluoride ions in calibration solutions**

| Calibration solution | Stock | 1 | 2 | 3 | 4 | Distilled water |
|---|---|---|---|---|---|---|
| Mean Potential (mV) | 23.33 | 40.90 | 58.37 | 81.53 | 99.17 | 216.37 |
| Concentration (g/l) | 9.998 | 4.993 | 2.503 | 1.002 | 0.0499 | 0.005 |

**Table 6: Concentrations (g/l) of fluoride ions in samples**

| Sample | Ganalé | Mariam | Moul | Si belle | Sunu ndox | Téranga |
|---|---|---|---|---|---|---|
| Mean Potential (mV) | 185.80 | 179.43 | 188.60 | 185.60 | 184.33 | 176.60 |
| Concentration (g/l) | 0.007 | 0.009 | 0.006 | 0.007 | 0.008 | 0.011 |

## Determination of chloride ions

**Table 7: Concentrations (g/l) of chloride ions in calibration solutions**

| Calibration solution | Stock | 1 | 2 | 3 | 4 | Distilled water |
|---|---|---|---|---|---|---|
| Mean Potential (mV) | 71.4 | 89.03 | 105.73 | 128.83 | 145.77 | 226.40 |
| Concentration (g/l) | 0.744 | 0.365 | 0.185 | 0.073 | 0.037 | 0.001 |

**Table 8: Concentrations (g/l) of chloride ions in samples**

| Sample | Ganalé | Mariam | Moul | Si belle | Sunu ndox | Téranga |
|---|---|---|---|---|---|---|
| Mean Potential (mV) | 124.4 | 141.3 | 123.2 | 146.2 | 140.6 | 121.0 |
| Concentration (g/l) | 0.09 | 0.04 | 0.09 | 0.04 | 0.05 | 0.10 |

## Result of the analysis of sodium by flame photometry

**Table 9: Concentrations (g/l) of sodium ions in calibration solutions**

| Calibration solution | Stock | 1 | 2 | 3 | 4 | Distilled water |
|---|---|---|---|---|---|---|
| Mean Current (mA) | 94.00 | 73.67 | 56.67 | 37.67 | 27.00 | 0 |
| Concentration (g/l) | 0.58 | 0.23 | 0.11 | 0.05 | 0.03 | 0.01 |

**Table 10: Concentrations (g/l) of sodium ions in samples**

| Sample | Ganalé | Mariam | Moul | Si belle | Sunu ndox | Téranga |
|---|---|---|---|---|---|---|
| Mean Current (mA) | 37.5 | 27.0 | 38.5 | 25.0 | 27.0 | 42.0 |
| Concentration (g/l) | 0.046 | 0.029 | 0.048 | 0.026 | 0.029 | 0.056 |

In general, volumes indicated on the pouch labels were different from the measured volumes, which is not a surprise due to the very informal nature of this type of business. In a study involving bottled water in Senegal, Sarr et al. [15] used ion chromatography and found a discrepancy between the values of the minerals listed on the label and the values measured.

Analysis of nitrates, fluorides, and chlorides ions were carried out using an electrochemical method that utilizes ion-specific electrodes. This method is fast, reliable, and inexpensive. However, a lot of precautionary measures were taken because of the fragility of the equipment and of the excessive sensitivity of the electrodes to temperature and pH changes, as well as to the presence of complexing agents, etc. For the sake of redundancy, each sample was subjected to three successive analyses.

Samples showed relatively high concentrations in nitrates: 50 mg/l for Ganalé, 60 mg/l for Mariam, Moul, Sunu ndox, and Téranga, and 70 mg/l for Si Belle (see tables 3, 4).

WHO recommends a maximum level of 25 mg/l of nitrates in water intended for consumption. European standards for drinking water established the following: levels of nitrates below 50 mg/l are recommended for water intended for consumption, levels between 50 mg/l and 100 mg/l are acceptable and those exceeding 100 mg/l do not comply. With these provisions, we can see that only the sample Ganalé met the European recommended nitrates level, while all the other samples had acceptable levels. The Sarr et al. [15] study found that one water sample out of 12 had nitrates level exceeding the Senegalese standards, which are the same as that of WHO.

Nitrates are not normally dangerous to human health. However, they can be reduced to nitrites which are toxic for humans.

The presence of nitrates at levels above the standards can be harmful to infants. Indeed, infants tend to consume large amounts of water relative to their weight, and their digestive system is immature and thus more conducive to the reduction of nitrates to nitrites. Nitrites can cause severe anemia from methemoglobinemia because they lead to the reduction of iron II in hemoglobin to iron III not suited for the transport of oxygen in the blood.

Studies have shown that nitrates and phosphates are very potent eutrophying agents. These are environmental pollutants beyond doses normally found in nature. These doses varying according to geographical areas [18].

Finally, as goiter-inducing molecules, nitrates are endocrine disruptors. They interact with the thyroid by curbing the ability of this gland to capture the iodine which is necessary to its functioning. These effects are also noted with thiocyanates and specially perchlorates that can develop additive or synergistic effects with nitrates [18].

The samples also presented relatively high fluorides concentrations compared to the standard set by WHO in drinking water (1.5 mg/l) (see tables 5, 6). The resulting levels ranging from 6 mg/l to 11 mg/l were 5-7 times higher compared to the WHO standard. These results are consistent with a study conducted in the same laboratory [2, 12].

In Senegal, the 1.5 mg/l recommendation is strictly applied and the public water company SDE (La Sénégalaise Des Eaux) has even lowered the level at 0.8 mg/l because our country is often characterized by temperatures above 20 °C, which results in an increased water consumption and therefore an increase of fluorides intake by body weight.

Relatively high water fluoride levels may be advised in countries with sometimes low fluoride levels in tap water. In France, for example, bottled mineral waters contain variable amounts of fluorine, ranging from less than 0.1 to 9 mg/l [9]. However, there still is a risk of fluorosis with the consumption of certain mineral waters with high fluoride levels [2, 13].

Dental fluorosis, which is irreversible, appears after months or years of consumption of high fluoride levels, 1.5 mg/day in children and 0.1 mg/kg in infants during the period of mineralization of teeth, which begins in the third month of life in the womb and ends at about 12 years of age. This condition is characterized by the appearance of white areas and sometimes brown spots on the teeth. A mild fluorosis does not affect tooth function but is generally considered a cosmetic problem [13]. When the severity of dental fluorosis increases, deeper layers are affected and can lead to toothaches and reduced chewing ability.

Fluorides are important for dental health. They act on the mineralization of the tooth and have an antibacterial effect protecting against tooth decay. The recommended maximum dose for the prevention of tooth decay in infants less than 6 months old is 0.01 mg/day and corresponds to the level of fluoride content in breast milk. For all other age groups, the recommended optimal dose is 0.05 mg/kg/day [13].

Excessive intake of fluorine at a dose of 0.2 mg/kg/day can cause skeletal fluorosis. It is manifested by an increase in bone density making bones more fragile. Skeletal fluorosis is a progressive condition not leading to death. Bones increase in density and become increasingly fragile. Skeletal fluorosis may be reversible (to some degree) depending on the extent of bone changes that occur. In less severe cases, skeletal fluorosis may be manifested by symptoms such as pain and stiffness in the joints. The most serious cases are manifested by reduced range of motion, deformation of the skeleton and increased risk of fracture. The most severe symptoms tend to affect the spine in the lower and supporting parts of the body. The age, nutritional deficiencies, kidney failure, bone remodeling and the dose and exposure to fluoride's duration may play a role in the onset of the disease [13]. Let us suppose that an infant and an adult of respective average body weights of 10 kg and 70 kg consume exclusively water from our samples. For an average daily consumption of 1 liter for the infant and 2 liters for the adult, we estimate their respective daily fluorides intake to be 0.6 mg/kg/day to 1.1 mg/kg/day for the infant, and 0.17 mg/kg/day to 0.31 mg/kg/day for the adult, which clearly puts them at risk of skeletal fluorosis.

Fluorides are naturally present in food (tea is rich in fluoride) [6, 13, 20], drinking water and dental hygiene products like toothpaste, mouthwash and fluoride supplements, and as gels and varnishes applied by dental professionals. Thus it would be important to consider all of these inputs when setting a maximum dose in drinking water.

The levels of chlorides in the samples ranged from 40 mg/l for Mariam and Si belle, 50 mg/l for Sunu ndox, 90 mg/l for Ganalé and Moul, to 100 mg/l for Téranga (see tables 7, 8).

French regulations advocate a content of 0.1 mg/l of free chlorine in water for consumption. However, a free chlorine level greater than 0.1 mg/l was allowed in order to benefit from the antibacterial properties of chlorine [5].

WHO tolerates up to 250 mg/l of chlorine content, beyond which its taste is perceptible in the water. Senegal, through the SDE, applies a dose of 250 mg/l of chlorides conform to WHO recommendations. All the samples studied contained chlorine levels consistent with the standards of both WHO and SDE.

The occasional overdose of chlorine in drinking water poses no health risk, because most often than not, consumers immediately recognize the smell and taste of chlorine in drinking water in case of overdose.

The sodium levels of the studied samples were obtained by flame photometry. They ranged from 26 mg/l for Si belle, 29 mg/l for Sunu ndox, and Mariam, 46 mg/l for Ganalé, 48 mg/l for Moul, to 56 mg/l for Teranga (see tables 9, 10).

For sodium, WHO makes no recommendations for sodium levels in water intended for consumption. However, for Senegal, the SDE recommends a maximum dose of 200 mg/l. All samples in this study exhibited levels lower than 200 mg/l.

Sodium is an important element in the metabolism of the body. A high intake of sodium has adverse consequences on the cardiovascular system (i.e. high blood pressure, heart and kidney failures).

Finally, studies [6, 13] have established a correlation between the levels of different minerals and the geographical origin of the water, its geological environment. A comparison between British bottled mineral waters and those of continental Europe [6], showed British waters to exhibit relatively low levels for most sought after minerals with the exception of barium. Italian waters gave higher concentrations of strontium and uranium and water from Slovakia and Czech Republic have higher levels of lead.

## CONCLUSION

The analysis of minerals in filtered and purified water sold in Senegal showed minerals levels in accordance with WHO and Senegalese standards for nitrates, chlorides and sodium, but not for fluorine levels which were significantly higher. These filtered and purified waters sold in plastic pouches being subject to significant consumption by the population, it would be extremely interesting and important to study their PET content because of the public health risks. Finally, a bacteriological study would help to better assess the quality of filtered and purified water sold in plastic pouches in Senegal.

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