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Groundwater physical and chemical characterization of some regions in Senegal: study on the representativeness of iron and manganese concentration in boring water

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Abstract

The majority of Senegal's groundwater has a surplus concentration of iron and manganese. The diagnosis of drilling water shows that more than 80% of the water collected in different areas of Senegal have high amount of those both elements. Their concentrations are higher than the WHO guideline value of 0.3 mg. L^{-1} and 0.05 mg. L^{-1}. While iron and manganese do not pose a serious health risk, their presence may indicate that groundwater is of poor quality and may be indicative of other problems that may have adverse effects on human health. The purpose of this study was therefore to characterize the groundwater of some areas in Senegal and to evaluate the representativity of iron and manganese in terms of concentration in order to provide elements of response to high concentrations in the water. To reach this objective, we applied the Principal Component Analysis (PCA) and Variance Analysis (ANNOVA) method of the Minitab^R version 17 software on physical and chemical analysis results in order to better interpret the results. Therefore, the characterization of the samples showed globally that the groundwater must be treated before consumption by the populations. The qualitative study made it possible to highlight that the Maastrichtian is the most exploited tablecloth like the other tablecloths. Thus, this present study has also shown that the groundwater collected in these different regions deserve to be purified before consumption by the populations because the following physical and chemical parameters: electrical conductivity, turbidity, sulphates, iron and manganese far exceed the potability standards accepted by WHO.

Keywords: Physical and chemical analysis, groundwater, iron, manganese, regions.

Introduction

Iron (Fe) and manganese (Mn) are metallic elements found in many types of rock. These two elements are also common in water and are essential, in small quantities, to all living organisms[1-3]. Many metamorphic and sedimentary rocks contain iron and manganese. It was noticed that in soil, iron and manganese are predominantly in oxide form[4,5]. In natural waters, they can have four different origins[6]: the rocks where they will be mainly in the form of carbonate; accidental pollution; soil drainage; accumulation in the reducing zone of reservoir dams. These metals do not present a major risk to human health[7,8], but they can cause problems in drinking water during its slow oxidation and precipitation in the water system distribution. These problems were summarized as following: they may give a metallic or bitter taste to the water; under certain conditions, deposits of iron oxide and manganese can occur causing certain inconveniences which are among others stains on the linen, fouling water softeners, degradation of the quality of the water due to a bacterial development on the chemical support of manganese oxide…protection of bacteria against the biocidal effect of chlorine[9,5].

In the context of achieving the Millennium Development Goals (MDG) in terms of access to water and sanitation, Senegal has installed a lot of drillings in rural areas since 1970[10]. Paradoxically, there are many problems relating to physical and chemical qualities in particular to: high levels of salt, fluorine, iron, manganese; the intrusion of undesirable elements from agricultural activities (pesticides, nitrates), mining (cyanide, arsenic and mercury); risks of deterioration of the bacteriological quality of water due to lack of treatment, maintenance of hydraulic structures or appropriate sanitation systems, poor transport and storage practices, unhygienic housing conditions.

The general objective of this study is to make a diagnosis of the state of play of the physical and chemical quality of drilling water in some areas of Senegal while evaluating its health and socio-economic impact on the population and the institutional system, organizational and regulatory. Indeed, the specific objective related to this study is to find out the representativity of iron and manganese in terms of concentration in the groundwater (drilling water). To reach this objective, the

Principal Component Analysis (PCA) and Variance Analysis (ANNOVA) method of *Minitab^R version 17* software were used for the statistical processing of physical and chemical analysis results.

Materials and methods

Presentation of the study area: To meet the water needs of the population facing the insufficiency of surface water that meets the standards of use, Senegal relies on the exploitation of groundwater resources through the establishment of many borings. These groundwater resources are contained in different aquifers that contain formations ranging from Quaternary to Maastrichtian. The sites chosen to implement our research are those of different regions in Senegal, particularly the case of Dakar, Thies, Louga, Saint Louis, Kaolack, Tambacounda and Ziguinchor. The choice of this distribution over different areas is important, to better see if there are disparities in the results of physical and chemical analyzes of groundwater according to their geographical location and the groundwater.

Sampling methodology: To find out the general quality of Senegal's groundwater, in particular the iron and manganese content, water samples were collected in June 2018 from 44 borings made by the Senegal National Water Company (SNWC). In this way, water sampling is a rather delicate operation to which the greatest care must be brought. The analytical results and the interpretation that will be given depend on the sampling. It is necessary to preserve the samples so that they are homogeneous, without modifying the physical and chemical characteristics of the water[11].

Samples were recovered from thirteen (13) borings in the Dakar region, eleven (11) in Thies, one (1) in Louga, two (2) in Matam, two (2) in Kaolack, four (4) in Tambacounda as well as eleven (11) in Ziguinchor. Samples and physical and chemical analyzes were facilitated by the Senegalese Water Company (SWC). To identify the samples, a number has been assigned to each vial. Sampling equipment has been given special attention. Thus, we used new polyethylene bottles. Before leaving the field, the flasks were first washed with tap water, then with 10% nitric acid and finally thoroughly rinsed with distilled water. In the field before filling the bottles, for safety reasons, they are washed three (03) times with the water to be analyzed, and then filled to the edge. Samples collected, carefully labeled and stored at 4°C in coolers are transported to the SWC quality control laboratory.

Methodologies and materials used for dosages: The pH and the electrical conductivity were measured *in situ* immediately after sampling. The pH was measured in the field using a Radiometer Analytical pHM201 portable pH meter and in the laboratory with a Hanna pH209 laboratory pH meter. The conductivity measurement was done in the field using a Hanna portable conductivity meter. The turbidity was measured by turbidity meter turbidity meter WAg-WT 3020. The sulphate and nitrate ions were determined by spectrophotometry or colorimetry using a Hach Lange DR 3800 spectrophotometer. The chloride ions were determined by the Mohr method. Calcium and magnesium ions were determined by complexometry using EDTA. Iron and manganese were measured in the laboratory by colorimetry with a molecular absorption spectrophotometer of the DR 2010/ Hach type.

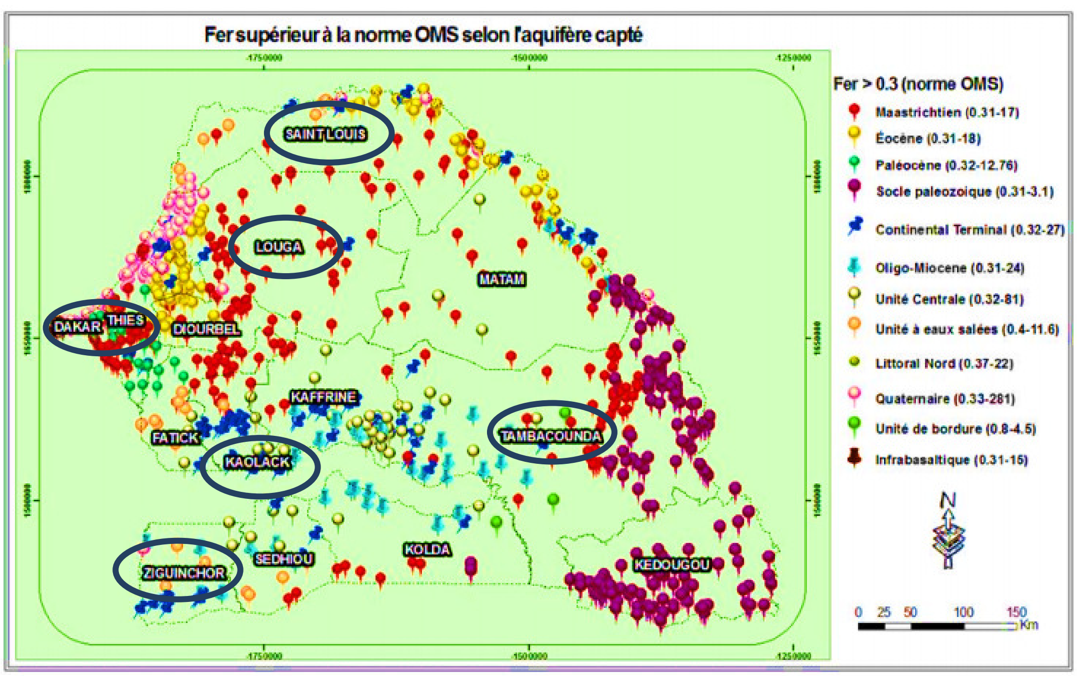

Figure-1: Iron level higher than the WHO standard according to the aquifer collected and location of the study areas[10].

Statistical analyzes: The *Minitab*^{R} version 17 statistical tool was used to analyze the physical and chemical results. The combined use of Principal Component Analysis (PCA) is a powerful tool for analyzing physical and chemical parameters of water and establishing geochemical models[12]. In addition, the Variance Analysis method was also used to better explain the data on 11 parameters or variables conductivity, pH, turbidity, Ca^{2+}, Mg^{2+}, NO_3^-, NO_2^-, Cl^-, SO_4^{2-}, Mn^{2+} and total iron (Fe^{2+} and Fe^{3+}).

Results and discussion

Physical and chemical characterization (Table-1) carried out on *in situ* measurements, (pH, electrical conductivity, turbidity) and the laboratory determination of major components and metallic trace elements (chloride Cl^-, sulphate SO_4^{2-}, nitrate NO_3^-, nitrite NO_2^-, calcium Ca^{2+}, magnesium Mg^{2+}, sodium Na^+, total iron (Fe^{2+} and Fe^{3+}), manganese Mg^{2+}) is made in seven (7) regions of Senegal.

Electrical conductivity: The measurement of electrical conductivity allows the mineralization of water to be evaluated quickly, but very roughly. The electrical conductivity values obtained varied between 211µS/cm to 1166.33µS/cm (Table-1). Of the 7 regions, it should be noted that 4 regions (Dakar, Thies, Louga and Ziguinchor) had conductivity values higher than the WHO standard of 300µS/cm. These waters are moderately mineralized[13].

pH: Most samples had a pH of 7 except for few samples. These water samples (Table-1) were basic and all remained within the WHO recommended pH range (6.5-8).

Turbidity: According to Table-1, only the regions of Dakar, Louga and Kaolack had turbidity values exceeding the WHO standard of 5NTU. Which means that these ground waters drilled in these areas were quite murky.

Chlorides: Table-1 indicates that chloride levels range from 20 to 247.8mg.L^{-1}, which is safe for water use as the WHO standard is 250 mg.L^{-1}.

Sulphates: The values of this parameter range between 0 and 280mg.L^{-1}, apparently all values are below WHO standards (250mg.L^{-1}). High sulphate values were measured in the Louga region.

Calcium: Calcium contents range from 38mg.L^{-1} to 212mg.L^{-1} (Table-1). None of these waters therefore has a concentration higher than the WHO standard of 100mg.L^{-1}, unlike the Dakar region where a calcium content of 212mg.L^{-1} is noted.

Magnesium: Magnesium varies at levels ranging from 35mg.L^{-1} to 102.1mg.L^{-1} (Table-1). These levels are lower than the norm accepted by the WHO for magnesium, which is 150mg.L^{-1}.

Nitrates: Nitrate levels vary during the study period (Table-1) from 0 to 11.88mg.L^{-1}. These values remain below the value allowed by the WHO standard of 50mg.L^{-1}. This is also the case of nitrite ions (NO_2^-).

Iron: The total iron concentrations as shown in Table-1 vary on average from 0.11 to 2.4mg. L^{-1}. Virtually all waters have levels exceeding the WHO standard of 0.3mg.L^{-1}.

Manganese: The levels of manganese in the analyzed waters vary from 0.07 to 0.12mg.$^{L-1}$ as can be seen in Table-1. The waters have concentrations higher than the WHO standard (0.05 mg.L^{-1}).

Like these results, we can draw a general conclusion that these waters deserve a physical and chemical treatment before consumption. On this basis, we made a qualitative study on the aquifer layers from which the groundwater (drilling water) comes. The results of this study are shown in the Figure-2.

Table-1: Characterization of drilling water of some areas in Senegal.

Régions	Conductivity µs/cm	pH	Turbidity NTU	Cl^- mg.L^{-1}	SO_4^{2-} mg.L^{-1}	Ca^{2+} mg.L^{-1}	Mg^{2+} mg.L^{-1}	NO_3^- mg.L^{-1}	NO_2^- mg.L^{-1}	Fe total mg.L^{-1}	Mn^{2+} mg.L^{-1}
Dakar	713,60^{a,b}	7,14^{b,c}	6,80^{b}	44,00^{a}	15,02^{a}	212,00^{b}	76,60^{a}	1,61^{a}	0,07^{a}	1,42^{b,c}	0,07^{a}
Thies	797,55^{a,b}	7,19^{c}	2,77^{a}	106,40^{a,b}	0,00^{a}	168,50^{a,b}	93,40^{a}	1,31^{a}	0,08^{a}	0,29^{a}	0,11^{b}
Louga	1122^{a,b}	7,66^{d}	7,02^{a,b}	30,00^{a,b}	280,00^{c}	136,00^{a,b}	84,00^{a}	0,80^{a,b}	0,13^{a}	0,47^{a,b}	0,132^{a}
Saint Louis	161,05^{a,c}	6,62^{a}	2,27^{a,b}	17,00^{a,b}	0,00^{a}	66,500^{a,b}	35,00^{a}	0,00^{a,b}	0,05^{a}	2,40^{c}	0,1^{a}
Kaolack	242^{a,c}	6,76^{a,b}	25,80^{c}	20,00^{a,b}	12,00^{a}	38,00^{a,b}	48,00^{a}	2,80^{a,b}	0,10^{a}	1,94^{b,c}	0,1^{b}
Tambacounda	211,50^{b,c}	7,16^{b,c}	1,45^{a,b}	25,00^{a,b}	2,50^{a}	51,50^{a}	41,50^{a}	1,40^{a,b}	0,09^{a}	0,11^{a}	0,08^{a}
Ziguinchor	1166,33^{b}	6,66^{a}	1,46^{a}	247,80^{b}	122,33^{b}	76,00^{a,b}	102,10^{a}	11,88^{b}	0,12^{a}	0,16^{a}	0,12^{a}

Results with the same letters in exponent on the same column are not significantly different.

The qualitative analysis (Figure-2) of the physical and chemical data on different sites shows that most of the Senegal's drilling water is captured from the Maastrichtian aquifer. In fact, from the 44 drilling sites analyzed, the study showed that twenty-six (26) of the samples come from the Maastrichtian aquifer, six (6) from the Paleocene limestones, five (5) Oligo-Miocene, one (1) Oligocene, two (2) Paleocene and four Paleozoic pedestal. In addition, the Maastrichtian is the most exploited aquifer in Senegal with borings sometimes reaching 500 meters deep with flows varying between 100 and 205m^3/h and low drawdowns. It also covers 4/5 of the territory with a potential of 500000 m^3/day.

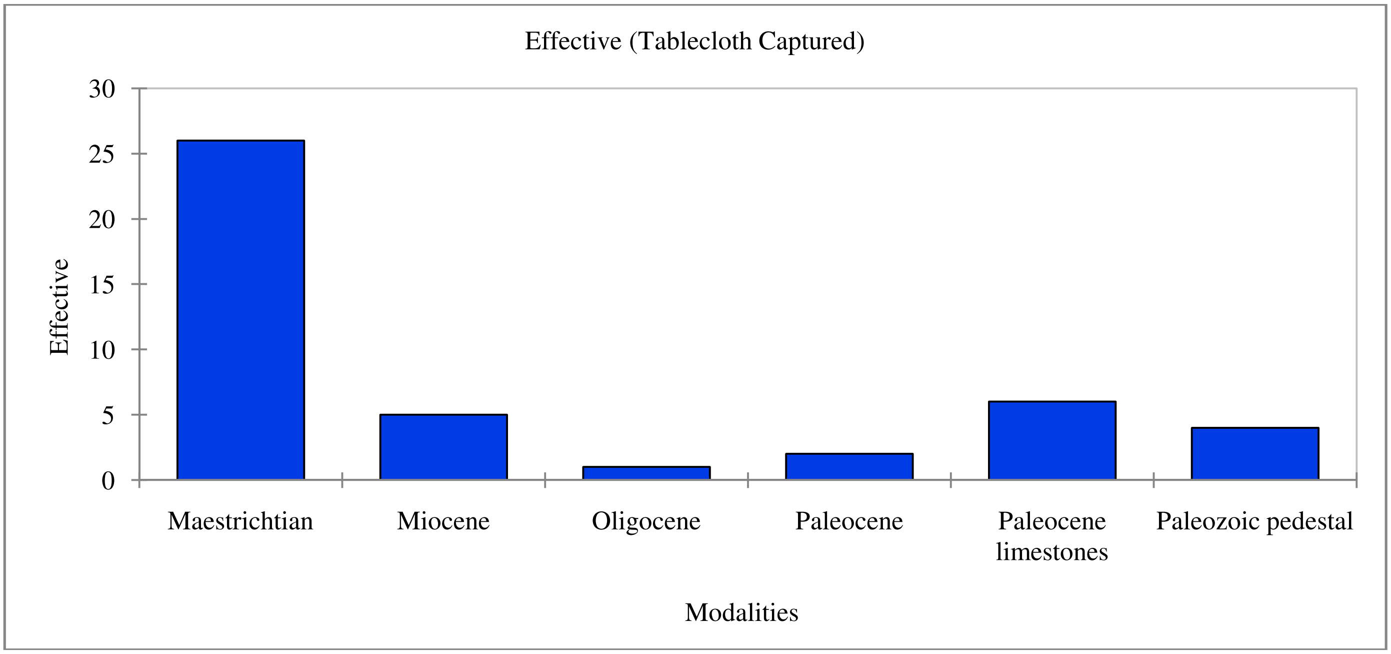

Figure-2: Bar chart of water tables in some areas of Senegal.

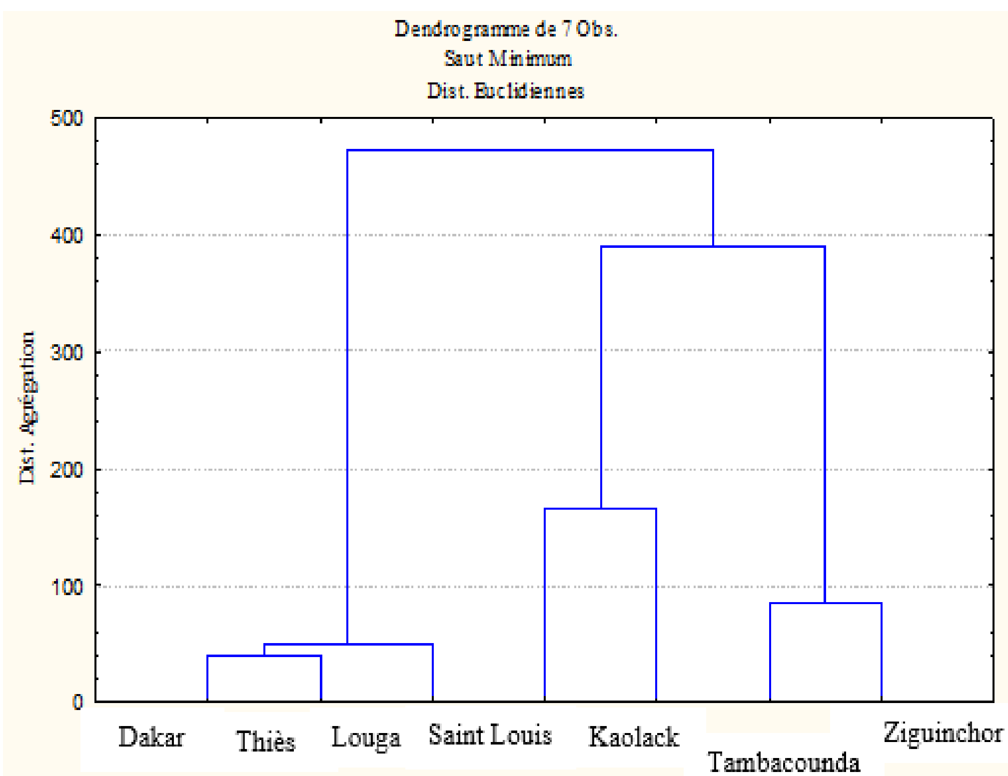

Figure-3: Dendrogram of the variables in the groundwater of Senegal.

The result of the hierarchical ascending classification on the physical and chemical variables is presented according to the regions (zones). Based on the distances and their position on the dendrogram, distinct classes and subclasses of regions emerge (Figure-3). The subclass defined by regions such as Dakar, Thies and Louga indicates that these three (3) regions have about the same physical and chemical parameters. In the same way, this is what is observed for the regions of Saint Louis and Kaolack as well as the regions of Tambacounda and Ziguinchor. In other words, the examination of Figure-3, allows us to say that statistically the regions of Dakar and Thies present physical and chemical results unlike the regions of Tambacounda and Ziguinchor. Indeed, this can be explained by the fact that geologically these areas do not have the same types of soil.The Dakar region is composed of a variety of calc-alkaline and alumino-potassium granitoid (two micas granites), metavulcanites, green rocks, and metasediments[14].

This form of representation (Dendrogram) is supported by the Figure-4.

The space of the variables in this plane indicates that the first factor is well correlated in its positive part with ions such as, NO_3^+, Cl^- and NO_2^- in the Ziguinchor zone. The region of Louga is correlated with sulphate and magnesium ions as well as conductivity, the Thies region is correlated with pH and calcium, in a smaller one with manganese. And finally, turbidity and total iron (Fe^{2+} and Fe^{3+}) are correlated with the regions of Saint Louis, Tambacounda and Kaolack. The correlation of the parameters shows the degree of representativeness in the different zones (regions). Concerning the iron and manganese we are interested in, this study shows that these elements are more to the east (Tambacounda), to the north (Saint Louis) and to the west center (Kaolack).

More specifically, we have shown (Figure-5 and Figure-6) the concentrations of iron and manganese as a function of the sampling area (region).

Examination of Figure-5 and 6 show that iron and manganese concentrations are higher than the World Health Organization (WHO) guideline of 0.3mg/L and 0.05mg/L for iron and manganese respectively. Indeed, we found that more than 80% of sample collection sites analyzed have levels above the standard of potability in terms of iron and manganese. This is observed, for example, in the regions of Matam, Kaolack and Dakar. In terms of geology, the latter are found in areas where the subsoil is of a calc-alkaline granitoid nature (biotite granite). The characteristic biotite and garnet of these rocks in these study areas are very rich in iron and manganese[14]. Iron and manganese are essential trace elements for the human body, but overloading the human body with these two elements can lead to primitive hemochromatosis (poor regulation of iron absorption by the intestine) and even liver cancer (risk of liver cancer). Hence the need to purify these elements in the drilling water before consumption by the populations.

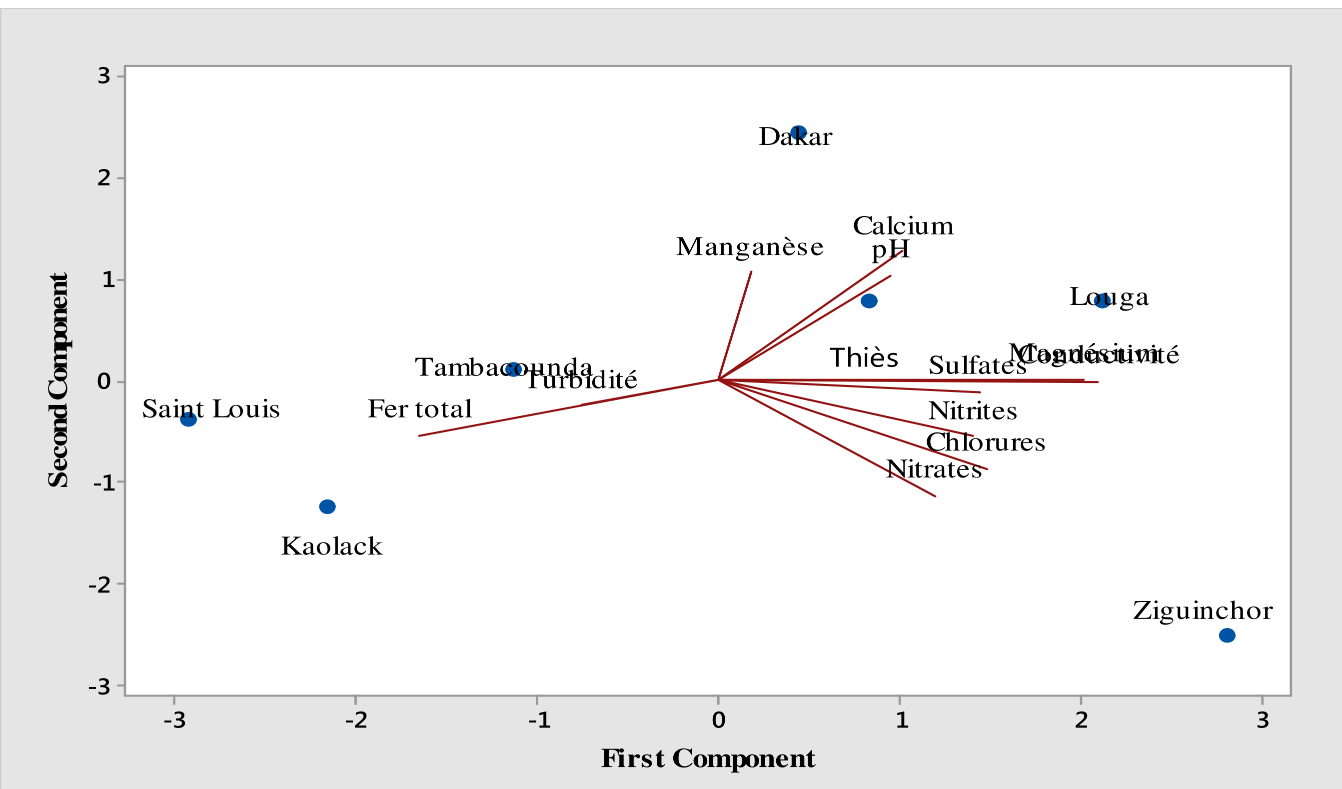

Figure-4. Principal Component Analysis (PCA) of Physical and chemical Parameters by Region.

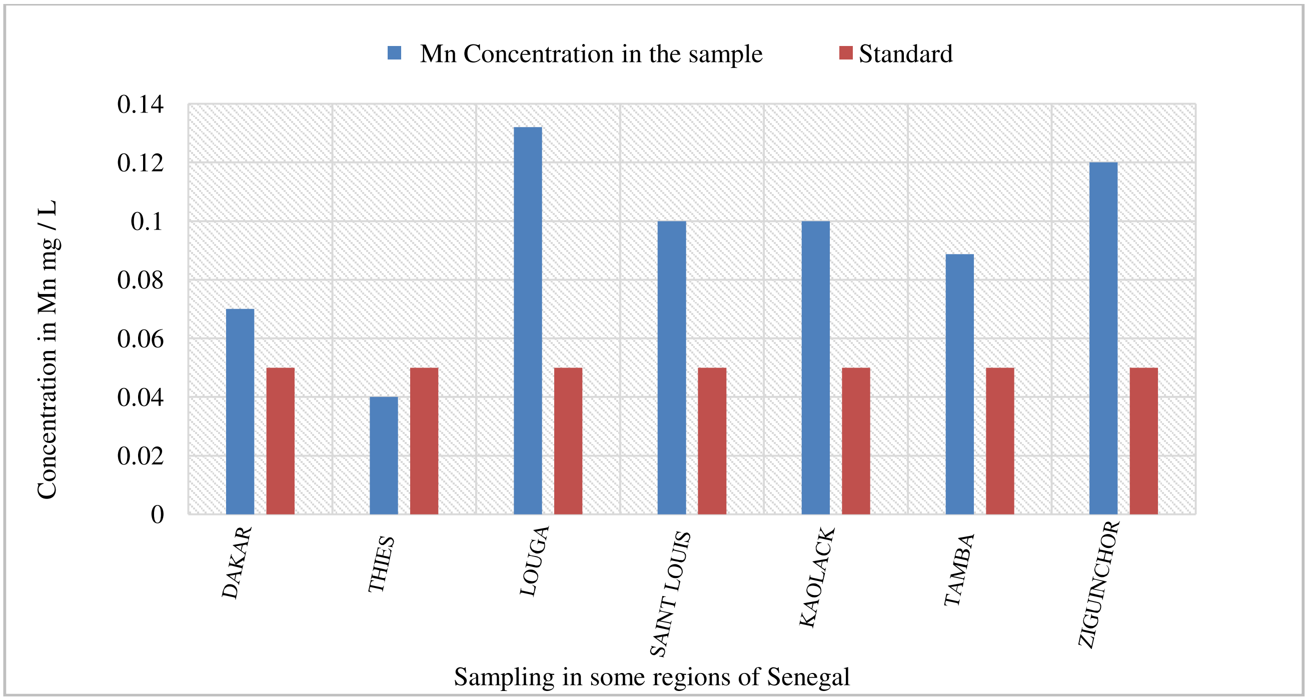

Figure-5: Bar graph comparing the manganese content with the potability standard.

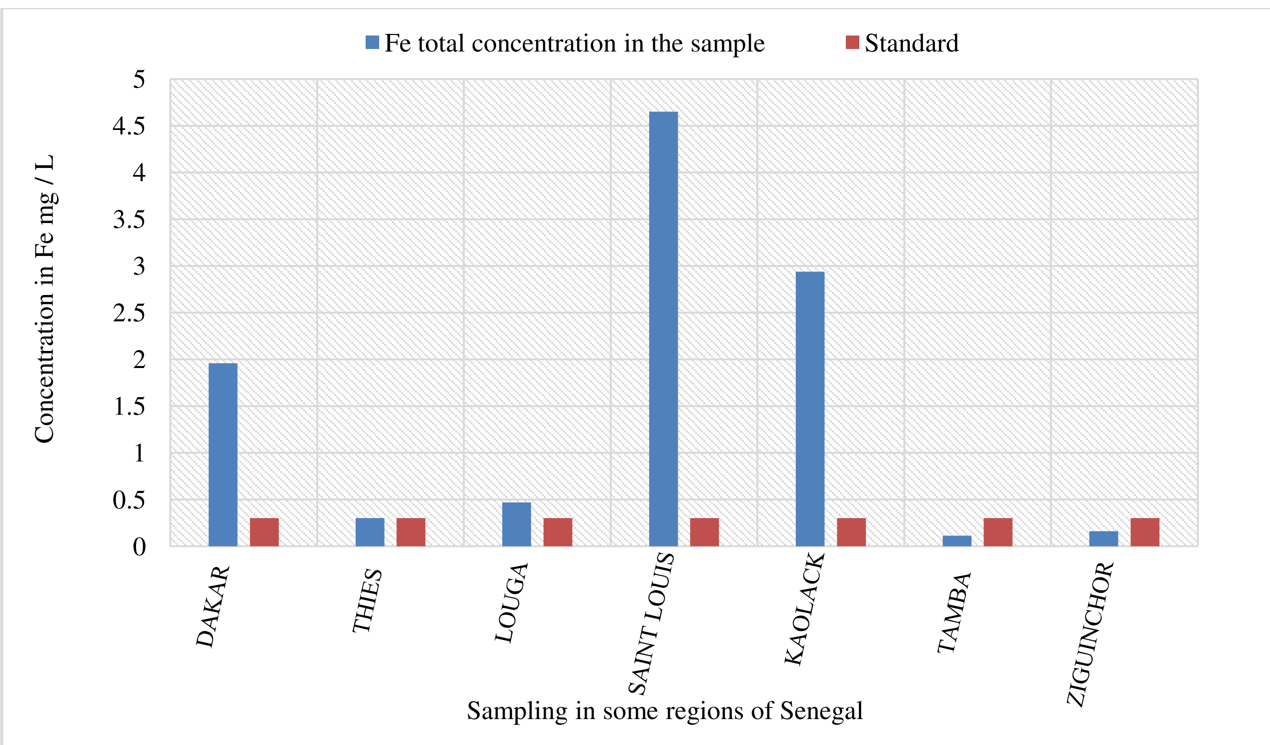

Figure-6. Bar graph comparing the iron content with the potability standard.

Conclusion

This paper came up with the possibility to determine the physical and chemical parameters of the groundwater of some zones (regions) in Senegal. Principal Component Analysis (PCA) and Analysis of Variance (ANNOVA) revealed the strong correlation between parameters and regions. This work highlighted the physical and chemical properties of the groundwater used before treatment and even to a lesser extent used as a source of drinking water, especially in the southern regions of Senegal. This study showed that these groundwater are not recommended for consumption as drinking water. The parameters that degrade these groundwater as drinking water are mainly iron, manganese, electrical conductivity, turbidity for some parts of Senegal. It is therefore necessary to proceed with a purification of these waters with a view to the elimination of certain metallic pollutants such as Fe^{2+}, Mn^{2+} and Fe^{3+}.

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