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Research Article

Determination of Physico-chemical Parameters of Well Water in the Central Niayes Area of Mboro (Senegal)

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Abstract

The Niayes of Mboro zone has significant hydro-agricultural potential and is marked by a diversity of crops. It is Senegal's main market-garden production zone. The Mboro area is characterized by a landscape of depressions and dunes resting on a shallow water table. There are generally no permanent watercourses, and the region's only significant water resource is the water table located in the quaternary coastal aquifers, which is influenced by several anthropogenic factors. The aim of this study was to determine the physico-chemical quality of water from four wells in the Mboro region, located in the hydromorphic zone of the Niayes. pH, temperature, total dissolved solids (TDS) and electrical conductivity (EC) were measured using a portable multiparameter, and chemical parameters by UV-visible spectrophotometry. The results show that the physical parameters comply with WHO standards (2000 for EC, 1000 for TDS and between 6.5 and 8.5 for pH), with the exception of the temperature of wells P2, P3 and P4, which varied between 25.9 and 28.4 ℃. The chemical study shows the presence of phosphate, sulfate, nitrate, fluoride and chloride ions at levels ranging from 0.1 mg/L (F^-) to 400 mg/L (Cl^-). The chloride content (400 mg/L) and $CaCO_3$ hardness (284.8 mg/L) in well P2 exceed WHO standards of 250 and 200 mg/L respectively. Phosphate (PO_4-P) ion levels in all four wells are equal to 0.8 mg/L. This value is higher than the recommended guide. This value is higher than the recommended guide value of 0.5 mg/L. Spatio-temporal variations in physico-chemical parameters appear to depend on the direction of water flow, the geological nature of the terrain crossed, the geographical position of the wells, the depth of the water tables tapped, industrial activities, the intrusion of marine water and the use of fertilizers. On the whole, the water from the wells studied is of good quality and suitable for irrigation and human consumption.

Keywords

Physico-chemical, Wells, Niayes, Mboro, Multiparameter, UV-visible Spectrophotometry

1. Introduction

In Senegal, and particularly in the Thiès region, the eco-geographical zone known as the northern littoral zone, the Niayes coastal zone or the Mboro zone, offers significant hydro-agricultural potential. This zone is marked by a diversity of crops. It is Senegal's main market-garden production zone. The Mboro area features a distinctive landscape of depressions and dunes resting on a shallow water table [1]. The climate is semi-arid [2]. As a result, crops must be heavily irrigated. There

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are no permanent watercourses in the Mboro area, and groundwater from Quaternary coastal aquifers remains the main source of water. Several factors can impact water resources in this locality. Intensive agriculture, mining activities and extractive and chemical industries such as Chemical Industries of Senegal (ICS) and Grande Côte Opérations (GCO) consume large volumes of water, which favors the intrusion of seawater into freshwater aquifers [3]. In addition, climate change, growing demographic pressure, salinization of water due to agricultural practices and intrusion of sea water are leading to physico-chemical changes in groundwater [3]. These anthropogenic pressures on groundwater are multi-faceted and can contribute to the deterioration of its quality. It is therefore important to study the physico-chemical quality of the water in this locality. It is against this backdrop that this study is being carried out. The aim of this work is to study the degree of pollution, by physico-chemical elements, of well water in the Niayes area of Mboro, used for drinking and market gardening.

2. Material and Method

2.1. Study Area

Niayes zone is located on the northern coastal fringe of Senegal. It extends from Dakar to Saint Louis over a length of 180 Km and a width varying between 5 and 30 Km [4]. This zone accounts for over 80% of Senegal's vegetable production. It is characterized by favorable physical conditions (climate, soil, hydrogeology), favoring agropastoral activities (horticulture, poultry and dairy production). The climate is Sahelian, hot and dry, with two seasons: a wet season from June to October and a dry season for the rest of the year. Rainfall is scarce, rarely exceeding 500 mm/year [5]. This zone is also characterized by a remarkable vulnerability of the water table, due to its shallow depth, which is outcropping during the rainy season and reaches 5 to 10 m at the height of the dry season.

This shallowness means that the corresponding unsaturated zone favours contamination from surface pollution. The groundwater table in the Niayes area is practically the region's only source of water. It also contributes to the water supply of the Dakar region, and is exploited by a battery of 6 boreholes with a flow rate of 7165 m^3/d [6].

The samples were taken in the Mboro area, more specifically between the communes of Darou Khoudoss and Mboro. This site is bounded by the Atlantic Ocean to the northwest and the Industries Chimiques du Sénégal (ICS) to the southeast.

It contains a basin that is the largest hydromorphic zone in the Niayes of Mboro, characterized by very high hydraulic and agricultural potential. Thus, the risks of pollution (salinization, contamination by pesticides and chemical fertilizers, industrial water discharges) already perceptible in the area are not negligible. In fact, groundwater monitoring data from Senegal's Water Resources Management and Planning Department (PAEP) indicate that it is already contaminated by nitrates [2].

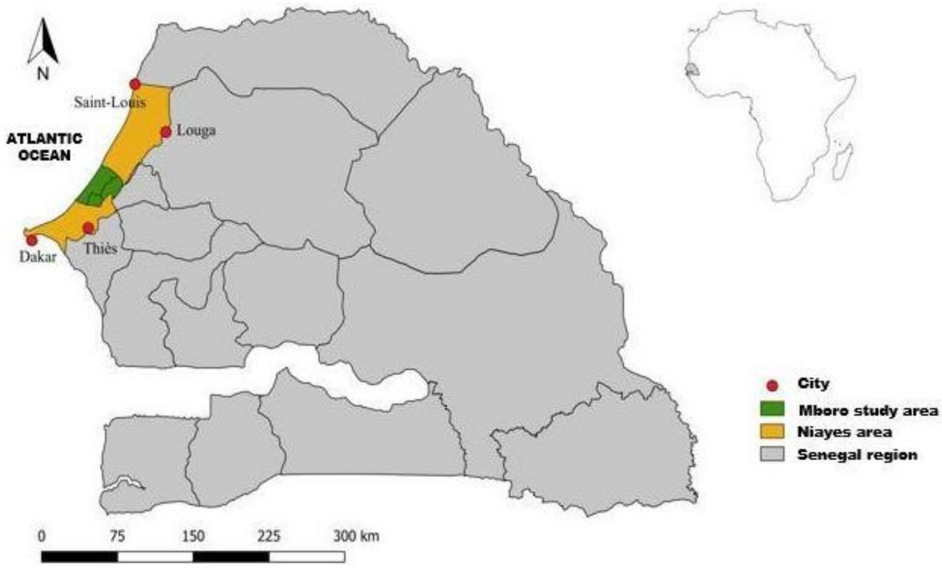

Figure 1. *Location of study area.*

2.2. Sample Collection and Storage

The sampling campaign was carried out in February 2020. Well water samples (P1, P2, P3 and P4) were obtained by slowly dipping a plastic bucket into the water without bubbling. Water samples were placed in 500 mL polyethylene bottles. The bottles were first washed with a detergent solution and rinsed with distilled water, then dried before sampling. During sampling, each bottle is rinsed with distilled water, followed by four (4) rinses with sampled well water. It is then sealed with a Teflon cap and placed in a plastic bag to avoid direct contact with sunlight. Water samples are transported and stored in a cool place at -4 ℃ before analysis.

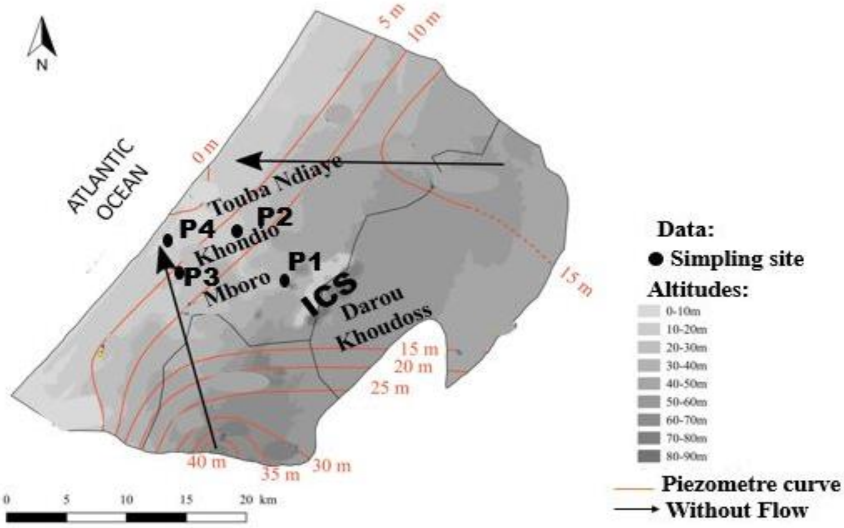

Figure 2. *Location of wells and physical characteristics of sampling site.*

Table 1. *Geographical coordinates, depths and distances from ICS and the sea of the wells studied.*

Sites	Coordinates Geographical	Depths (m)	Distances from ICS (km)	Distances from the sea (km)
P1	15.12363 -16.86572	2.8	2.96	7.73
P2	15.15751 -16.88209	3.6	7.1	4.15
P3	15.14743 -16.91433	3.2	8.85	1.92
P4	15.15746 -16.92206	8.7	10	0.561

2.3. Measurement of Physico-chemical Parameters

Physical parameters (temperature, pH and electrical conductivity) were measured in-situ using a combined pH-meter, HANNA instruments pH/ conductivity HI 98129. For pH measurement, the instrument was calibrated with buffer solutions pH=7.01 and pH=4.01. First select pH mode with the SET/HOLD button, then immerse the electrode in the sample water. Wait a few seconds for the stability symbol at the top of the LCD screen to disappear, then read the pH value displayed.

For Electrical Conductivity (EC) and Total Dissolved Solids (TDS), the device has been calibrated by immersing the probe in HI 7031 clean calibration solution (1413 µS/cm). Use the SET/HOLD button to select EC and TDS mode, then proceed in the same way as for pH. Plastic beakers are often used to minimize any electromagnetic interference. Temperature is displayed directly at the bottom left of the screen when measuring pH, EC or TDS.

2.4. Principle of Photometric Analysis

The blank can consist of the sample to be analyzed, without the reagent standard solutions. To prepare the sample for analysis, standard reagents are added to 5 mL of sample water. It is very important to respect the order and time prescribed in the analysis protocol to ensure that the reagents react with the substance to be analyzed.

To perform the assay, first switch on the instrument, then select the mode indicated (Visocolor, Visocolor Eco or Nanocolor) in the protocol and the filter number for the element to be assayed. Filter numbers range from 1 to 6, each

zero must be set before each measurement to establish a zero reference. To do this, place the tube containing the blank in the measurement well and press the zero button. The photometer displays zero and indicates that the sample is ready for analysis. Then place the prepared sample in the measurement well and press the M button to obtain the concentration of the element to be analyzed directly on the instrument display in mg/L.

3. Results and Discussion

3.1. Results of Physico-chemical Analyses of the Well Water Studied

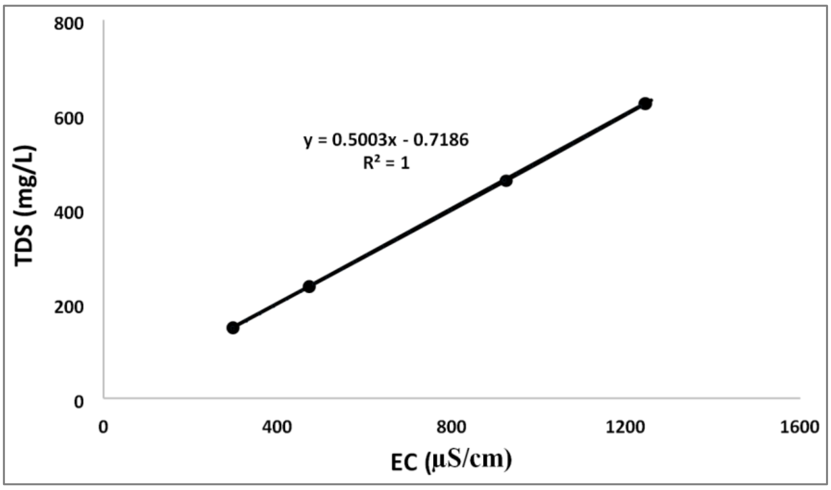

Figure 3. Correlation between Electrical Conductivity and TDS of well water.

Table 2. Physico-chemical parameters of sampled well water.

Wells / Parameters	Units	P1	P2	P3	P4	Average ±σ	Standards
pH	-	7.25	6.88	6.88	6.65	6.915 ±0.215	6.5 et 8.5
T	°C	22.1	28.2	28.4	25.9	26.150 ±2.536	25
EC	µS/cm	473	1244	925	298	735.000 ±372.422	2000
TDS	mg/L	236	623	460	149	367 ±186.326	1000
$CaCO_3$		80.1	284.8	186.9	115.7	166.875 ±78.192	200
Ca^{2+}		26.52	92.56	46.28	32.04	49.350 ±25.968	100
Mg^{2+}		4.27	12.82	17.1	8.54	10.682 ±4.781	50
K^+		< LD	3	5	< LD	4.000 ±1.000	15
Cl^-		120	400	230	40	197.500 ±134.976	250
F^-		0.2	0.4	0.3	0.1	0.250 ±0.111	1.5
SO_4^{2-}		48	190	146	< LD	128.000 ±59.352	250
NO_3^-		20	< LD	< LD	23	21.500 ±1.500	50
PO_4-P		0.8	0.8	0.8	0.8	0.800 ±0.000	0.5

LD: Device Detection Limit

The results obtained during this campaign show that the parameters are generally variable from one well to another. The pH varies slightly between 6.65 and 7.25 for the wells studied. On average, it is close to neutral with a more or less alkaline character. The pH of the wells studied decreases slightly as we approach the P2, P3 (6.88) and P4 (6.65) coasts. This decrease correlates with the direction of groundwater flow in the area, from the mainland to the sea (Figure 2, Table 1). So pH variations can be associated with the origin of the water, the geological nature of the substrate and the watershed crossed [7]. Nevertheless, they remain within the range recommended by the WHO (6.5-8.5). Temperature varies between 22.1 and 28.4 ℃. This variation may depend on factors such as the geographical positions of the wells and/or their depths. The temperature values recorded are all above the average temperature for the region (21 ℃) at the sampling period (February). This suggests that the influence of ambient temperature is negligible. In addition, the temperatures recorded in wells P2, P3 and P4, 28.4, 28.2 and 25.9 ℃ respectively, are higher than the standard temperature (25 ℃). The water in wells P2 and P3 has more or less the same pH and temperature values. However, this similarity cannot be established between wells P1 and P4, which are further apart. As far as these two parameters are concerned, the use of these well waters may not present a health hazard for consumers.

The Electrical Conductivity (EC) of the water varies between 298 (low mineralization) and 1244 µS/cm (high mineralization). It is directly proportional to the quantity of mineral salts dissolved in the water, with a perfect correlation, R^2 =1 (figure 3). Furthermore, the electrical conductivity values of wells P2 (1244 µS/Cm) and P3 (925 µS/Cm) are much higher than those found in wells P1 and P4.

Indeed, the more superficial the water, the more it is exposed to evaporation and the higher its concentration of dissolved salts [8].

On average, the conductivity of these waters is comparable to that found by DIALLO et al (2015) at Keur Saer [9]. However, it is well below the conductivity of the water table in an area of heavy industrial pollution at Darou Karim and Diorga Cherif in the Dakar region, respectively 6196 and 4260 µS/Cm [10]. They are also lower than the conductivity found by Bouchemal et al (2015) in the wilaya of Biskra (Algeria), where the majority of values at the twelve sites exceed 2000 µS/cm [11]. Furthermore, the conductivity of these waters is well above that of well waters from the commune of Sinthiou Malème in the Tambacounda region (Senegal) respectively 258 and 231 [12]. However, the electrical conductivities of the well waters studied remain below the standard set by the WHO (2000 µS/Cm). The $CaCO_3$ concentrations of wells P2 and P3 show the highest values, respectively 284.8 and 186.9 mg/L. The water in these two wells is considered very hard, $CaCO_3$ content above 180 mg/L [13]. The latter generally depends on the geological structure of the soils crossed [14]. Mining activity in ICS could be at the origin of the high hardness of well water [13]. TDS analysis of well water shows that it is of good quality [15]. The TDS values obtained in the four (4) wells during this campaign are higher than the averages found by HANE et al (2020), in the Tambacounda region, 143.87 and 112.50 mg/L [12]. Water from well P2, with a chloride ion content of 400 mg/L, does not meet the WHO standard (250 mg/L). Low potassium levels were recorded only in wells P2 and P3, with values of 3 and 5 mg/L respectively. Nitrate ions were not detected in these two wells, with concentrations of 20 and 23 mg/L respectively in wells P1 and P4. Phosphate (PO_4-P) levels found in all four wells during this campaign were all equal to 0.8 mg/L. This suggests that the presence of phosphate ion is independent of the geographical location and depth of the wells. This value is higher than the average value (0.35 mg/L) found by AHOUSSI et al (2010) in well water from the commune of N'zianouan (Ivory Coast) [16]. It is also higher than the maximum permissible value for groundwater (0.5 mg/L) (Table 2).

The lowest values for physical parameters such as pH, electrical conductivity and TDS, as well as anions with the exception of nitrate and phosphate ions, were recorded in well P4, which is deeper and closer to the sea. This well is therefore unaffected by marine water intrusion. On the other hand, well P2, 3.6 m deep and 7.1 and 4.15 km respectively from the ICS and the sea, and well P3, 3.2 m deep and 8.85 km from the ICS and 1.92 km from the sea, had the highest values for all parameters except nitrate and phosphate ions. Agricultural activities around this well are very intense, which could explain these high levels. With regard to the results obtained, we can conclude that the variations in physico-chemical parameters in the various wells, with the exception of nitrate and phosphate ions, probably depend on the direction of water flow, the geological nature of the terrain crossed, the geographical position of the wells and the depth of the water tables tapped. However, variations in nitrogen and phosphate compounds may depend on other factors, such as the agricultural and industrial activities that are very present in the area.

During this campaign, chloride (Cl^-), sulfate (SO_4^{2-}) and $CaCO_3$ ions had the highest mean values, at 197.5, 166.88 and 128 mg/L respectively. For the same parameters, these levels are well below the values found by DIME et al (2020) for the Darou Karim water table in the commune of Rufisque, respectively 696.45, 277.29 and 213 mg/L [10]. These high chloride concentrations in wells P1, P2 and P3 could be due to sea spray, evaporation of chlorine from the ocean, but above all to the intrusion of marine waters, caused by a drawdown of the water table around the ICS [17].

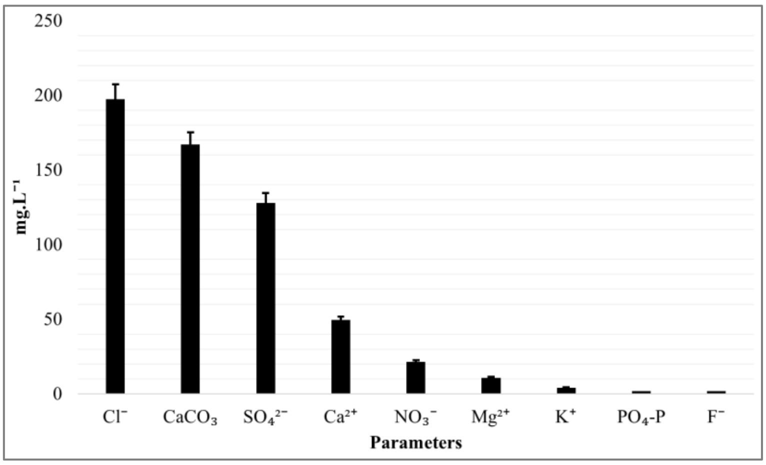

Figure 4. *Average levels of the chemical parameters studied in the wells.*

Sulfate ion levels seem to derive from the dry deposits observed in the environment. According to a survey of farmers, these deposits are sulfuric acid from runoff from the ICS. Average Ca^{2+}, Mg^{2+} and NO^{3-} ions levels are 49.35, 10.68 and 21.5 mg/L respectively. They are also much lower than those found by DIME et al (2020), respectively 272.04, 79.69 and 474.10 at Darou Karim and 219.22, 50.61 and 238.96 at Diorga Cherif. The presence of calcium and magnesium ions reflects the dissolution of rocks, deposits and other calcareous minerals such as dolomites [18]. PO_4-P and F^- ions are the lowest, with averages of 0.8 and 0.25 mg/L respectively. These low levels of fluoride ions may be due to the frequent renewal of the water table [10]. The concentrations of nitrate, sulfate and chloride ions found during this campaign are well above the levels found in the waters of the Diack area, commune of Ngoundiane, which are 5.9, 6.02 and 11.2 mg/L respectively.

3.2. Statistical Analysis

Table 3. *Pearson correlation matrix for well water physico-chemical parameters.*

Parameters	**pH**	**T (℃)**	**EC (µS/cm)**	**TDS (mg/L)**	**$CaCO_3$ (mg/L)**	**Ca^{2+} (mg/L)**	**Mg^{2+} (mg/L)**	**K+ (mg/L)**	**Cl^- (mg/L)**	**F^- (mg/L)**	**SO_4^{2-} (mg/L)**	**NO_3^- (mg/L)**	**PO_4-P (mg/L)**
pH	1												
T (℃)	-0.661	1											
EC (µS/cm)	0.011	0.699	1										
TDS (mg/L)	0.010	0.698	1.000	1									
$CaCO_3$ (mg/L)	-0.302	0.821	0.935	0.936	1								
Ca^{2+} (mg/L)	-0.200	0.677	0.904	0.906	0.973	1							
Mg^{2+} (mg/l)	-0.457	0.934	0.691	0.688	0.700	0.516	1						
K+ (mg/L)	-0.153	0.809	0.784	0.780	0.684	0.519	0.949	1					
Cl^- (mg/L)	0.065	0.615	0.987	0.988	0.931	0.938	0.572	0.672	1				
F^- (mg/L)	0.166	0.582	0.988	0.988	0.878	0.867	0.600	0.738	0.986	1			
SO_4^{2-} (mg/L)	0.066	0.683	0.993	0.993	0.895	0.849	0.716	0.829	0.968	0.988	1		
NO_3^- (mg/L)	0.065	-0.792	-0.950	-0.948	-0.862	-0.762	-0.859	-0.938	-0.887	-0.921	-0.970	1	
PO_4-P (mg/L)	-0.712	-0.057	-0.677	-0.675	-0.378	-0.385	-0.259	-0.544	-0.674	-0.775	-0.733	0.655	1

Using the results obtained, a correlation of the various parameters studied is sought. The Pearson correlation matrix reveals that the majority of parameters are positively correlated with each other. On the other hand, nitrate is negatively correlated with the other elements, with the exception of pH. Electrical conductivity is strongly correlated with Ca^{2+}, Mg^{2}+, Cl^{-}, F^{-}, SO_4^{2-} and $CaCO_3$, with coefficients ranging from 0.904 (EC/Ca^{2+}) to 0.993 (EC/ 0.993). Likewise TDS with correlation coefficients ranging from 0.906 (TDS/Ca^{2+}) to 0.993 (TDS/SO_4^{2-}). These ions are the main salts dissolved in water and are probably responsible for the high conductivity. The correlations between: SO_4^{2-}/ (0.968); F^-/Cl^- (0.986); SO_4^{2-}/F^- (0.988); $CaCO_3$/ Ca^{2+}(0.973) and Ca^{2+}/ Cl^-(0.938) are very strong. This suggests that these ions have common origins.

4. Conclusion

At the end of this study, analysis of the physico-chemical parameters shows that temperatures in wells P2, P3 and P4 are above the standard temperature (25 ℃). On the other hand, TDS, EC and pH values in these same wells remain within WHO recommended limits. For well P2, the electrical conductivity (1244 µS/cm) and TDS (623 mg/L) indicate high mineralization, and the chloride ion content is well above the WHO standard (250 mg/L). Chloride (Cl^-), sulfate (SO_4^{2-}) and calcium ($CaCO_3$) are the most prevalent in the wells studied, with respective averages of 197.5, 166.88 and 128 mg/L. The phosphate concentration in the four wells was 0.8 mg/L, above the guideline value of 0.5 mg/L. Spatio-temporal variations in physicochemical and chemical parameters, with the exception of nitrate and phosphate ions, probably depend on the direction of water flow, the geological nature of the terrain crossed, the geographical position of the wells and the depth of the water table tapped. The industrial activities of the Chemical Industries of Senegal (ICS), the intrusion of marine waters through overexploitation of the water table and the massive use of fertilizers have a major impact on well water contamination. These measurements also showed a perfect correlation between TDS and conductivity (R^2=1). Conductivity is also strongly correlated with Ca^{2+}, Mg^{2}+, Cl^{-}, F^{-}, SO_4^{2-} and $CaCO_3$, with coefficients ranging from 0.904 (EC/Ca^{2+}) to 0.993 (EC/ $CaCO_3$). Therefore some of these parameters govern conductivity and these may have common origins. Overall, the well waters studied are of good quality. Their use for irrigation and as drinking water is safe for human health. In addition, the study of Metal Trace Elements (MTE) and pesticides in this very intense agricultural zone is fundamental to better assess the quality of these waters.

Abbreviations

EC	Electrical Conductivity
GCO	Grande Côte Opérations
ICS	Chemical Industries of Senegal
LD	Device Detection Limit
MTE	Metal Trace Elements
PAEP	Water Resources Management and Planning Department
TDS	Total Dissolved Solids

Conflicts of Interest

The authors declare no conflicts of interest.

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