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Groundwater Quality Assessment in the Coastal Quaternary Sandy Aquifer in Darou Thiam-Ségoul Thioune-Fass Boye Axis (Niayes Area, Senegal)

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Abstract The "Niayes" area plays a major role in the Senegalese economy due to a very high market garden production. This "Niayes" area produces almost all of Senegal's vegetables (onions, potatoes, carrots, green cabbage, tomatoes, cherries, eggplants, lettuce and chili). Water supply to meet irrigation needs in this area comes mainly from groundwater resources. This Groundwater pumping has harmful consequences on the behavior on the groundwater piezometric level drop. Since 1987, the piezometric dome observed in this aquifer experienced a water level drop of 2.5 m at Taïba and Tawa Fall areas. The electrical resistivity tomography (ERT) shows the presence of a saturated and an unsaturated zones in the presence of dry sandy dunes with a thickness of about 12 m resting on a saturated zone corresponding to the aquifer captured by the 2 boreholes and the piezometer. Chemical analyzes showed an Electrical Conductivity values equal respectively to 269, 470 and 1110 µS/cm at Fass Boye piezometry, Darou Thiam and Ségoul Thioune wells. Electrical Conductivity value of 1110 µS/cm indicates a strong groundwater mineralization. This mineralization is correlated with Na^+ concentration of (145 mg/L) close to pollution by salt resulting in salinization of water making them unsuitable for consumption and irrigation. Water samples at Fass Boye piezometer and Ségoul Thioune well show low to medium mineralization because the electrical conductivities are respectively in the order of 269 and 470 µS/cm. Majors ions concentration (Cl^-, Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-}, HCO_3^-) with respective maximum concentrations of 140.84; 48; 21.32; 8.81; 78 and 122 mg/L, meet all World Health Organization standards for drinking water. Applying the Piper diagram to these groundwater samples shows a sodium and potassium chloride facies associated with proximity to the sea.

Keywords: *Niayes, groundwater, water quality, electrical conductivity, electrical resistivity tomography*

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1. Introduction

The "Niayes" area is the coastal zone located in the North-West of Senegal riding between four administrative regions: Dakar, Thiès, Louga and Saint-Louis. This region is strategic for the Senegalese economy of as it concentrates more than 80% of market gardening production (onions, potatoes, carrots, green cabbage, tomatoes, cherries, eggplants, lettuce and chili)., fruit and vegetables over a total area of 9,000 ha [1]. Its importance for Senegal is linked to their belonging to both the coastal domain and the continental domain [2]. This area, due to its geology and hydrogeology, is strategic in supplying drinking water to populations and in market gardening (onions, potatoes, carrots, green cabbage, tomatoes, cherries, eggplants, lettuce and chili). Water is the second limiting factor in these activities and undoubtedly the most essential. The drop in rainfall to which the Sahel had suffered obvious consequences on market gardening activity (onions, potatoes, carrots, green cabbage, tomatoes, cherries, eggplants, lettuce and chili) with the drying up of ponds and backwaters. This situation strained users to resort to groundwater resources located mainly in the Quaternary coastal sands to meet the many agricultural, industrial and mining needs. Numerous studies have focused on the hydrogeological characterization of this costal north sandy formation [1,3-12]. These various studies have shown that pumping rate from this sandy aquifer reached 21.547.317 m^3 in 2011 [13]. This pumping has led to a groundwater level decline and a tendency to pollution (nitrogenous, salty) threatening all market garden production [14]. Pesticide pollution is often noted in this agricultural area due to the leaching of organics and inorganics fertilizers used. Pesticides at concentrations greater than 0.1 µg/L (dicofol, chlorpyrifos and dimethoate) is also noted in places [15].

The vulnerability of the groundwater resource in the area is linked to the low depth of the water table, combined with the permeability of the essentially sandy sedimentary formation on the one hand. On the other hand, the piezometric evolution with a significant and continuous water level decline since 1952 [16] and the advance of the salt wedge to 120 m from [17] are also threats to the groundwater resource.

The objective of this study is to characterize the groundwater quality of the north costal aquifer. This latter is used to satisfy water supply of the populations of Darou Thiam, Ségou Thioune and Fass Boye villages in the presence of strong market gardening activities requiring large water demand.

2. Methodology

2.1. Study Area

The study area is located in the western part of Senegal between latitudes 15° and 16°08' North and longitudes 16 °13' and 17°17' West. It extends over 2300 km^2 from Kayar to Saint Louis (Figure 1). It is located in the sub-Canary climate zone despite its Sahelian latitude with a short rainy season extending from July to October and a longer dry season subdivided into sub-seasons. The wind regime in the study area is especially marked by the maritime trade wind direction NNW which predominates and greatly reduces the impact of the « harmattan » or the monsoon, which gives the coastal zone a mild local climate.

From a pedological point of view, six types of soils occurs in the study area. These soil types distributions vary from north to south around large geomorphological groups in series of dunes alternating with inter-dune basins [18,19]. In fact, in a broader framework concerning the study area, there are non-leached ferruginous "Dior" type soils and they come in several categories. "Deck" soils or lowland hydromorphic soils (inter dunes) which are rich in calcium and clay, suitable for market gardening and fruit crops. "Deck-dior" soils or clayey sands which are favorable to cereal and vegetable crops. "Tanghor" soils or lateritic soils which are very difficult to cultivate. The general problems encountered in these soils are: isolation, silting up, residual saltiness, poor organic matter, rapid lowering of the water table, water logging during wintering and rainfall variation.

From the geological standpoint, this region belongs to the Senegalese-Mauritanian basin, the largest coastal basin of northwest Africa [20]. Most of the geological formations encountered correspond to thickness reaching several thousand meters. At the outcrop appear almost exclusively Quaternary sediments sandy and sandy clay, especially alluvial and wind deposit. The best-known facies in the area are dated from the Cretaceous to the Quaternary [1,17,21,22,23,24].

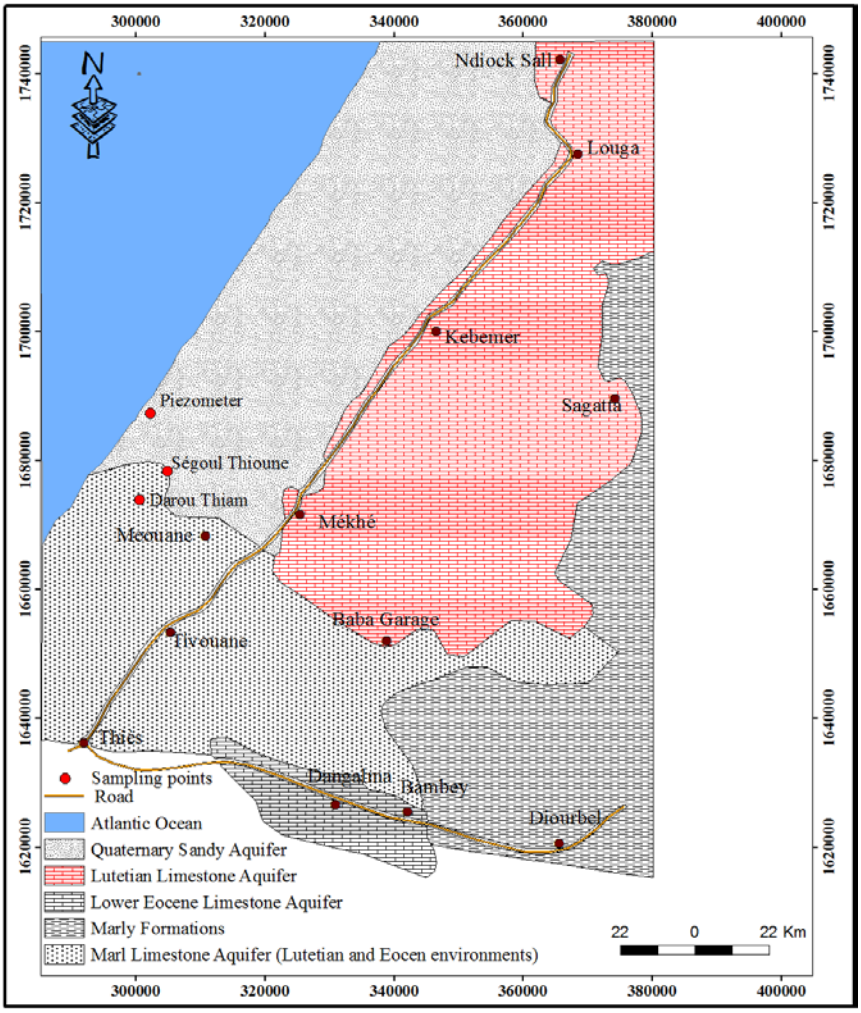

Figure 1. Geological map of the study area (Goeter, 2009, modified) [25]

The north coastal aquifer is characterized by Quaternary sandy dune formations between Kayar and Saint-Loius. Together with the Lutetian limestone in the Louga region, the lower Eocene limestone of Bambey and the lower Eocene marl-limestone in the Baba Garage region layers, it constitutes the hydraulic system of the north coast (Figure 2). This system ensures the drinking water supply for the urban and rural populations of Tivaouane, Kébémer, Louga, Bambey and Diourbel departments. It also covers the water needs for agricultural and pastoral activities of these localities as well as those of the industrial sector such as the mining operations of ICS, MDL and GCO. This system also supports the water supply to Dakar and its surrounding cities.

The general pattern of the groundwater flow is from on either side of a line oriented SW-NE and passing to the west of the Dakar-Saint Louis national road.

The permeability values of the north coastal aquifer are variable and range from $5.5.10^{-4}$ m/s to 8.10^{-2} m/s. Transmissivity values varies as a function of the thickness of the sands and are between $2.5.10^{-5}$ m^2/s and $8.9.10^{-4}$ m^2/s.

These different parameters and their values play an important role in the groundwater recharge processes by infiltration, the efficiency of which depends on the size of the soil particles and the aquifer formation.

The quaternary sandy aquifer is an unconfined aquifer that extends over 2300 km^2. It is mainly recharged by rainwater infiltration [26]. It is a large reservoir of water that flows slowly towards the ocean by gravity. Generally of good quality, these waters are however sensitive to anthropogenic pollution, especially if they are very exploited with an intensive use of the resource by households, market gardeners and industries often leading to a drop in piezometry [1,23].

2.2. Piezometric Measurement and Sampling

The purpose of this study is to map groundwater salinization using ERT and chemical analysis methods. An electrical probe was immersed in the wells until an audible signal is obtained. The value of the depth obtained is the static level of the water table (the depth + the edge of the well). A measurement of the coping makes it possible to deduce the real depth of the static grounwater level. The GPS used in the field gives the altitude in relation to the reference of the position measurements (the ellipsoid), we will consider the Z in relation to the reference of the altitude measurements which is the geoid. The acquired values are recorded in Table 1.

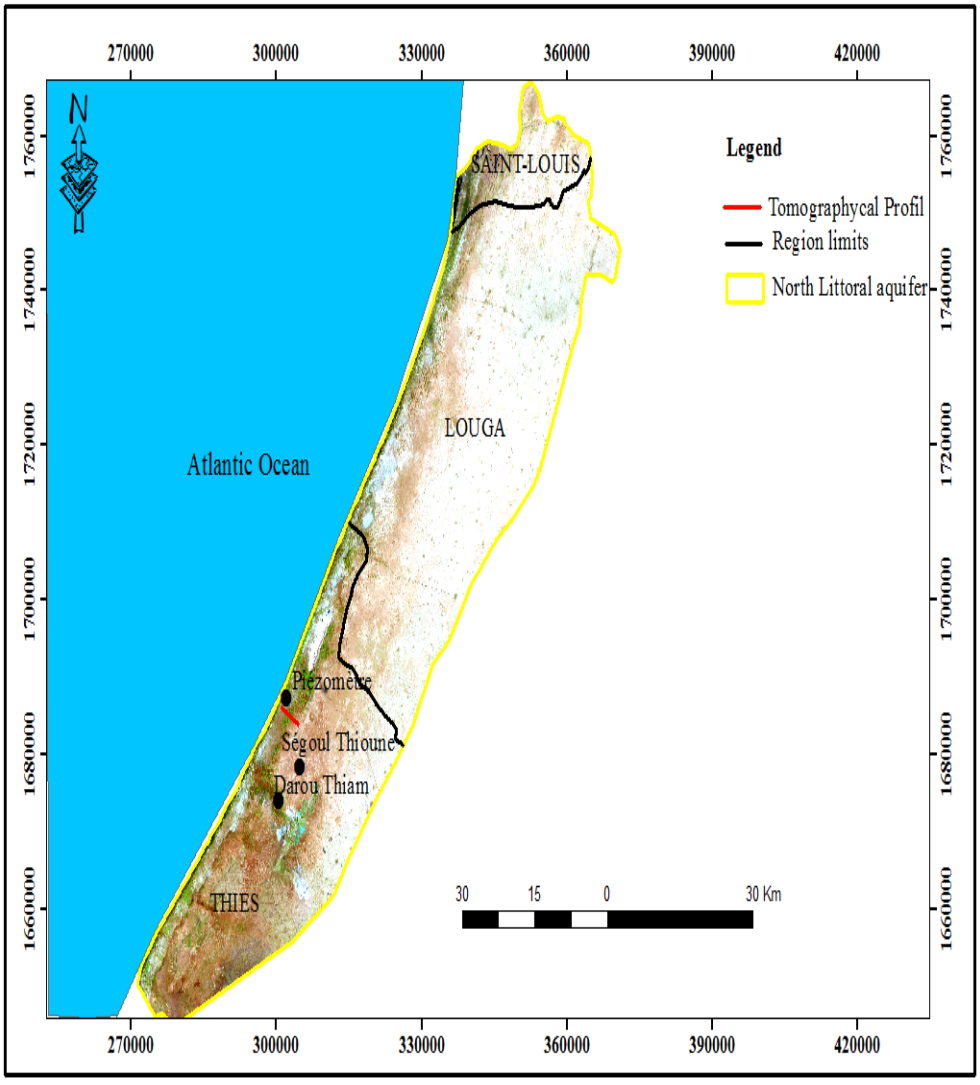

Figure 2. Hydrogeological map of the study area

Table 1. Positions and characteristics of the wells and the piezometer

Samples	Contact details in X (m)	Contact details in Y (m)	Altitude Z (m)	Depth with coping (m)	Coping (m)
Darou Thiam	300.665	1.673.950	60	17,39	1
Ségoul Thioune	304.911	1.678.322	71	27,74	0,42
Piezometer	302.280	1.687.325	38	12,86	1

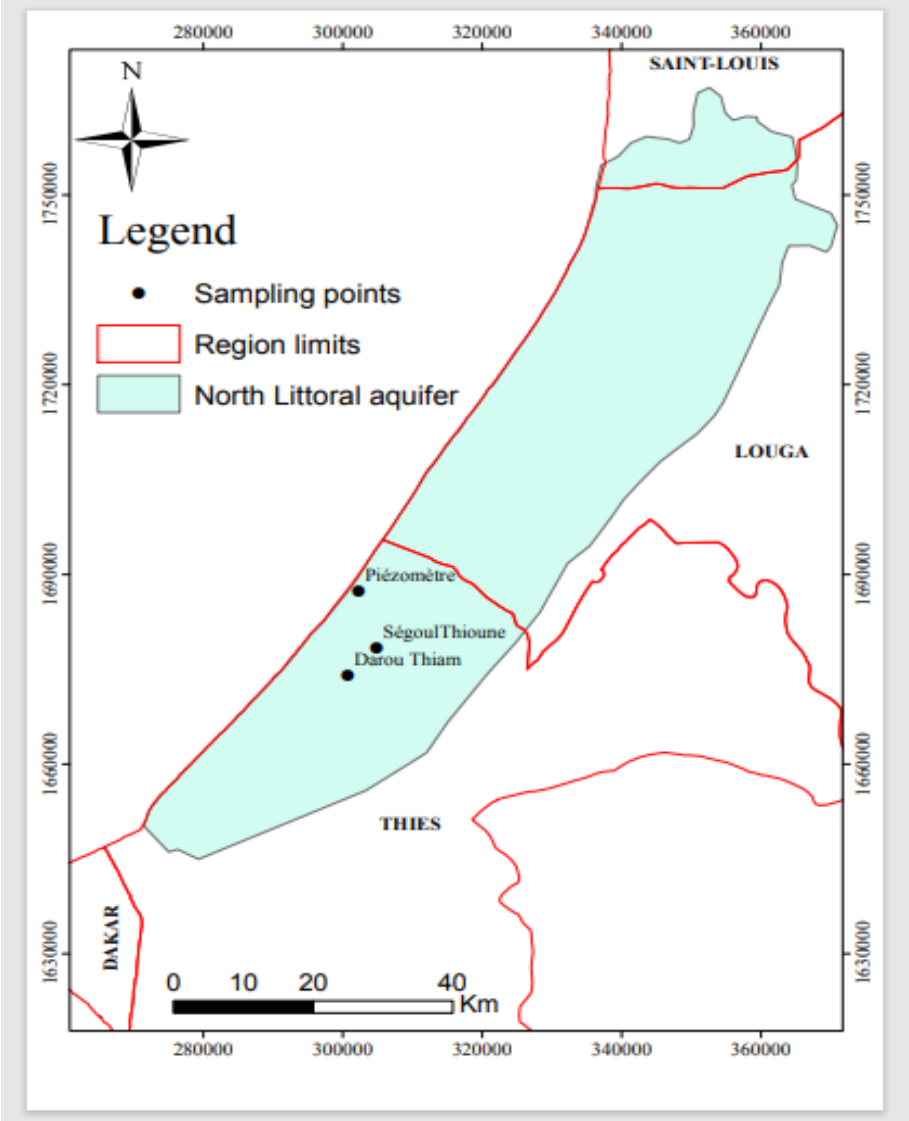

Figure 3. Samples positioning in study aera

Water samples were taken from the Darou Thiam, Ségoul Thioun wells and Fass Boye piezometer. The positions of which are shown in Figure 3. Groudwater samples were analyzed at the chemistry laboratory of Geology Department, UCAD. Major ions were measured by ion chromatography Dionex DX 120.

2.3. Tomography

Tomographic investigation is carried out with the Schlumberger method on an axis of 200 meters in length corresponding to a depth of 40 meters with the use of 41 electrodes and 42 jumpers. Electrical Resistivity Tomography (ERT) provides an "electrical image" of the subsoil, from surface resistivity measurements (Figure 3 and 4). In the case of 2D tomography, the distribution of resistivities varies vertically and horizontally along the profile. In other words, it is a "resistivity cut" to a depth of up to a hundred meters. The materials used for the realization are electrodes, 100 m cable rolls, a power source (battery), jumpers and hammers. This technique was used at the level of the piezometer area at Fass Boye.

For data acquisition, 42 electrodes are placed in a contour and connected to a multi-conductor cable. The electrodes are spaced 4 meters apart along the profile. Each electrode has a unique digital address in the device, which allows it to be identified by the computer. A measurement suite or acquisition protocol is installed on the computer. The protocol defines the electrode quartets to be used successively as injection electrodes and as measurement electrodes. The protocol is transmitted sequentially to an electrode selector which executes it by selecting the relevant electrodes. The measurement is automatically stored in memory.

3. Results

3.1. Tomography

Results show resistivity values varying between 40 ohm.m and 5500 ohm.m. In detail, Figure 4 shows that the low resistivity values (30 to 57 ohm.m) located on either side of the starting point indicate the presence of sands saturated with highly mineralized water (salinization). Areas of average resistivities (83 to 350 ohm.m) are also represented there. Finally, there are also areas of high resistivities represented by the dry dune sands (510 to 1500 ohm.m).

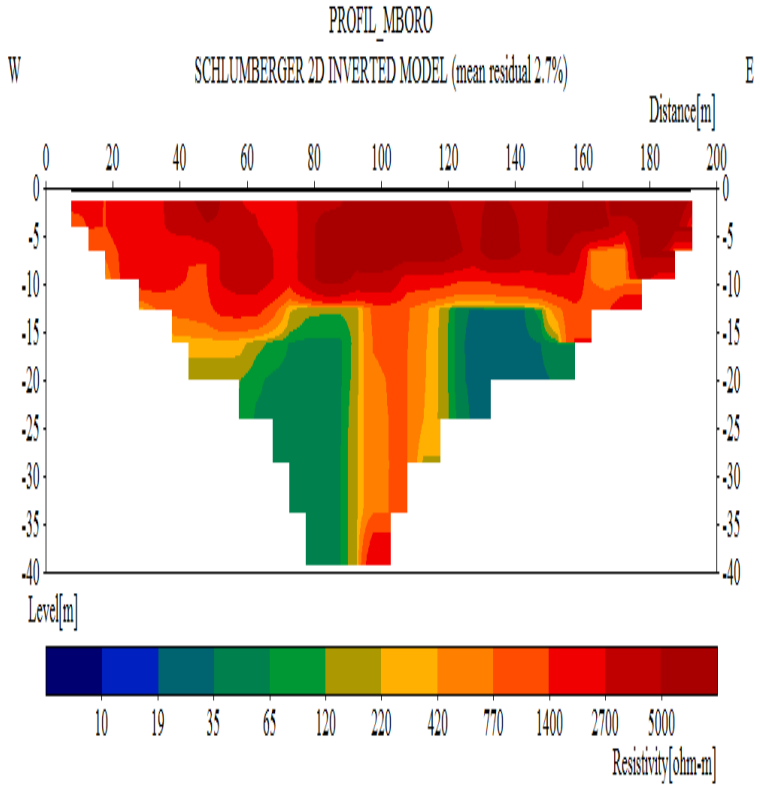

Figure 4. Tomographic resistivity profiles

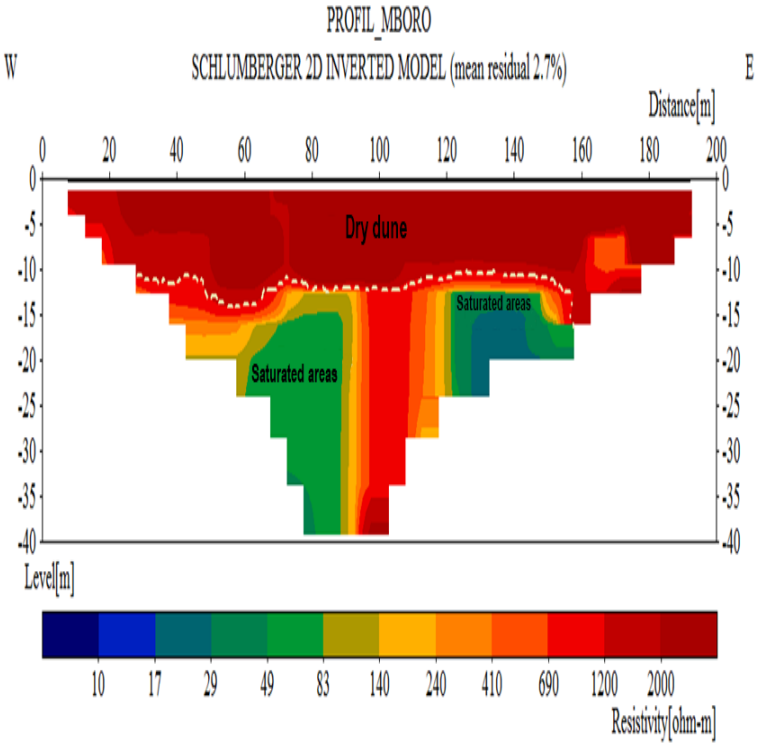

Figure 5. Tomographic profiles

These results show the presence of dry dunes with a thickness of about 12 m resting on a saturated zone corresponding to the aquifer captured by the 2 boreholes and the piezometer (Figure 4 and Figure 5).

3.2. Physico-chemical Characteristics of Water

Results from physico-chemical analyzes carried out on water samples are shown in Table 2. pH and electrical conductivity (uS/cm) were measured in situ while anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-) and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+ and Fe^{2+}) were analyzed by Dionex Ionic Chromatography and atomic absorption spectrophometry in hydrochemical laboratory of Cheikh Anta Diop University in Dakar (Table 2). Combination of these results compared to drinking-water potability standards (World Health Organization) will make it possible to assess the water quality in villages concerned by this study (Figure 5 to Figure 9).

Table 2. Physico-chemical characteristics of water samples

		µs/cm	mg/L								
Samples	pH	EC	HCO3-	Cl-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe^{2+}
Darou Thiam	6,39	1110	122	140,84	78,56	214,43	48,3	21,63	145,38	8,81	0,34
Ségoul Thioune	6,87	470	91,5	41,55	88,87	7,36	24,27	7,65	57,52	4,51	3,71
Piezometer	6,92	269	67,1	38,98	20,69	3,27	12,02	6,32	31,07	3,34	1,68

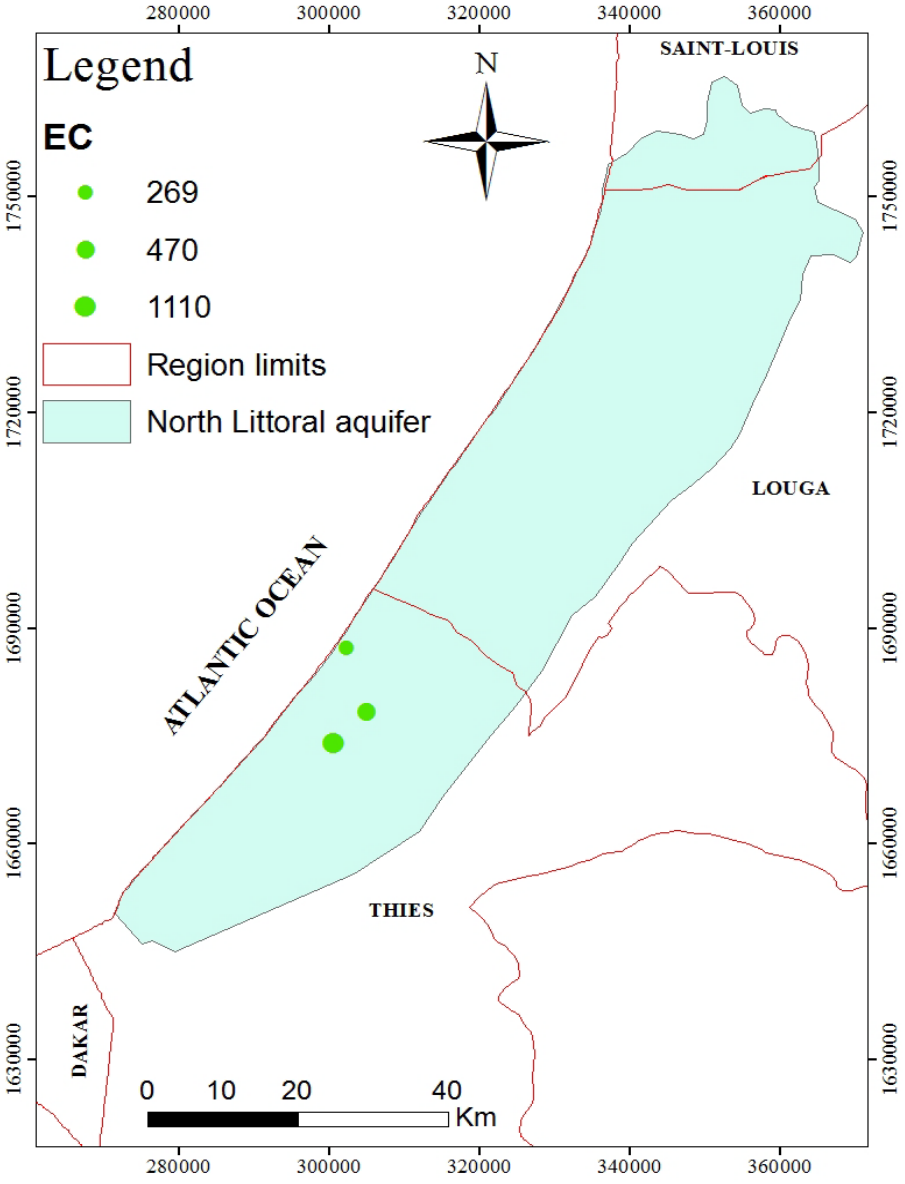

Figure 6. Change in electrical conductivity in the study area

Groudwater Electrical Conductivity values measured from wells and piezometers ranged between 269 and 1110 µS/cm (Figure 6). Electrical Conductivity values are in order of 269; 470 and 1110 µS/cm respectively at Fass Boye (piezometer), Ségoul Thioune and Darou Thiam. The latter site presents a high mineralization of groundwater. However, from Fass Boye to Ségoul Thioune we observe the passage of weak to medium mineralization.

From a potability point of view for drinking water, all waters meet the World Health Organization standard of 2000 uS /cm. According to the method of the United States Salinity Laboratory Staff (USSLS) of River Side in California, the samples from the piezometer and from Ségoul Thioune are in class C2, i.e. water at medium risk of salinization (electrical conductivity between 250 and 750 uS/cm). From an agricultural practical point of view, these 2 waters can be used without restrictions. Darou Thiam's sample is in class C3 (electrical conductivity ranged between 750 and 2250 uS/cm) and is characterized by a high risk of salinization.

For alkalinity, the Darou Thiam sample has a pH of 6.2 slightly more acidic than the water from the 2 other wells which are more close to neutrality (Ségoul Thioune with a pH of 6.87 and the piezometer for a value of 6.92) thus respecting the standard 6.5-8.5. OMS (1974) [27] have shown that for pH values less than or equal to 8.30, the alkalinity of water is essentially linked to bicarbonate ions (HCO_3^-). This is in perfect correlation with the presence of bicarbonates in water between 67.1 and 122 mg/L. In fact, at very low pH values, the carbonate species are essentially in the form of carbonic acid. This relative low pH value (acidic) is due to the presence of peatlands that oxidize organic matter.

Their sodium ion (Na^+) contents are between 31 and 145 mg/L. The waters of the village of Ségoul Thioune and the piezometer show low Na^+ values below the drinking water standard established by the World Healht Organization of 150 mg/L for drinking water. On the other hand, the Darou Thiam drilling water is close to salt pollution (145 mg/L) (Figure 7).

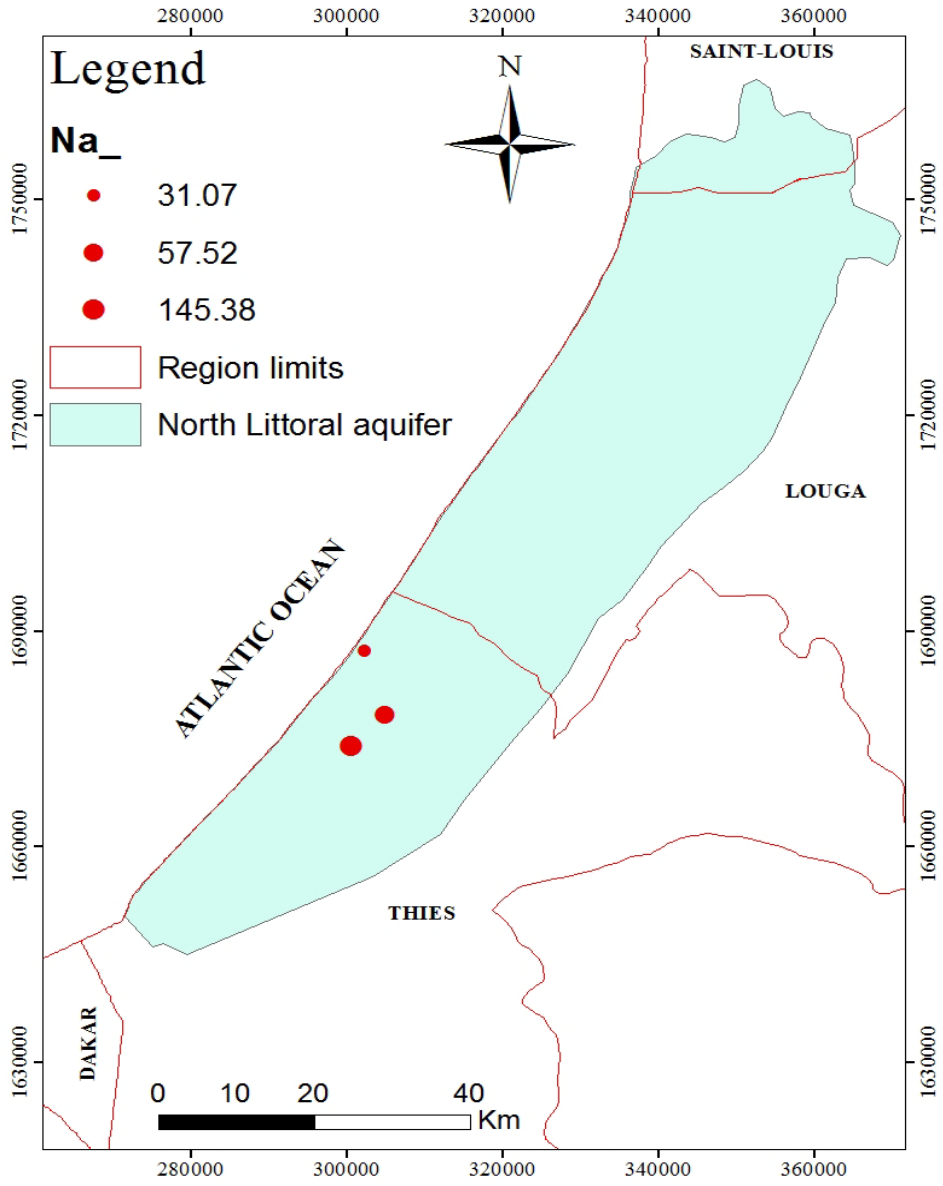

Figure 7. Distribution of sodium in the study area

Nitrates contents vary between 3.27 and 214.43 mg/L. The maximum value of 214.43 mg/L is observed in the village of Darou Thiam, largely exceeding the drinking standard (50 mg/L). The other well water complies with the World Health Organization standard with values equal to 3.27 and 7.33 mg/L respectively (Figure 8). This presence of nitrates is mainly due to anthropogenic actions in the area. Indeed, the high concentration of market gardening activities using nitrogen fertilizers and pesticides may be a cause of this nitrate pollution. On the other hand, poor management of household waste (household garbage, latrine water) could also be a possible cause. The combination of these 2 pollution cases can be found in the study area.

For nitrates, the maximum value of 214.43 mg/L is observed at Darou Thiam village, largely exceeding the standard of drinkability (50 mg/L). Nitrate contents of other wells (3.27 and 7.33 mg/L) complies with the World Health Organization standard.

Chloride (Cl^-) ions in all 3 samples show values below the maximum limit set at 200 mg/L by the WHO as being 140.84; 41.55 and 38.98 mg/L (Figure 9) (Figure 8). According, in unpolluted water, the value is often less than 10 mg/L and even less than 1 mg/L. The groundwater at study points contains no less than 38.98 mg/L of Cl^- which can be attributed to leaching from landfills or to the effect of sea spray (wet or dry precipitation).

The sulphates (SO_4^{2-}) values observed vary from 20 to 78 mg/L, far less than the admissible limit content (250 mg/L). The origin of the sulphates can be the dissolution of gypsum which is a hydrated calcium sulphate (Ca^{2+}, $S0_4^{2-}$, $2H_20$) or the indirect marine inputs linked to rainwater where mineralization is dominated by $S0_4^{2-}$ ions after Na^+ ions [27,28]. The Ca^{2+}, Mg^{2+} and K^+ ions are present at concentrations varying according to the sampling points (Ca^{2+} from 12 to 48 mg/L, Mg^{2+} from 6 to 21.32 and K^+ from 3.33 to 8.81 mg/L). All of these cations meet the potability standards established by the World Health Organization (Ca^{2+} standard = 270 mg/L, Mg^{2+} standard = 50 mg/L, K^+ standard = 12 mg/L). However, the Ca^{2+} values present must probably to be related to the marl-limestone substratum or the waters of the Lutetian limestone aquifer. The presence of Mg^{2+} ions in the samples has 2 probable origins. Magnesium is a relatively abundant element in the earth's crust; consequently, it is always included in the composition of natural waters in contact with granite, dolomite or limestone [27]. The presence of Mg^{2+} can also come from sea spray which has infiltrated with the rainwater [29]. Potassium ion can come from a low intake by domestic water which can contain up to 21 % of mineral residues [29].

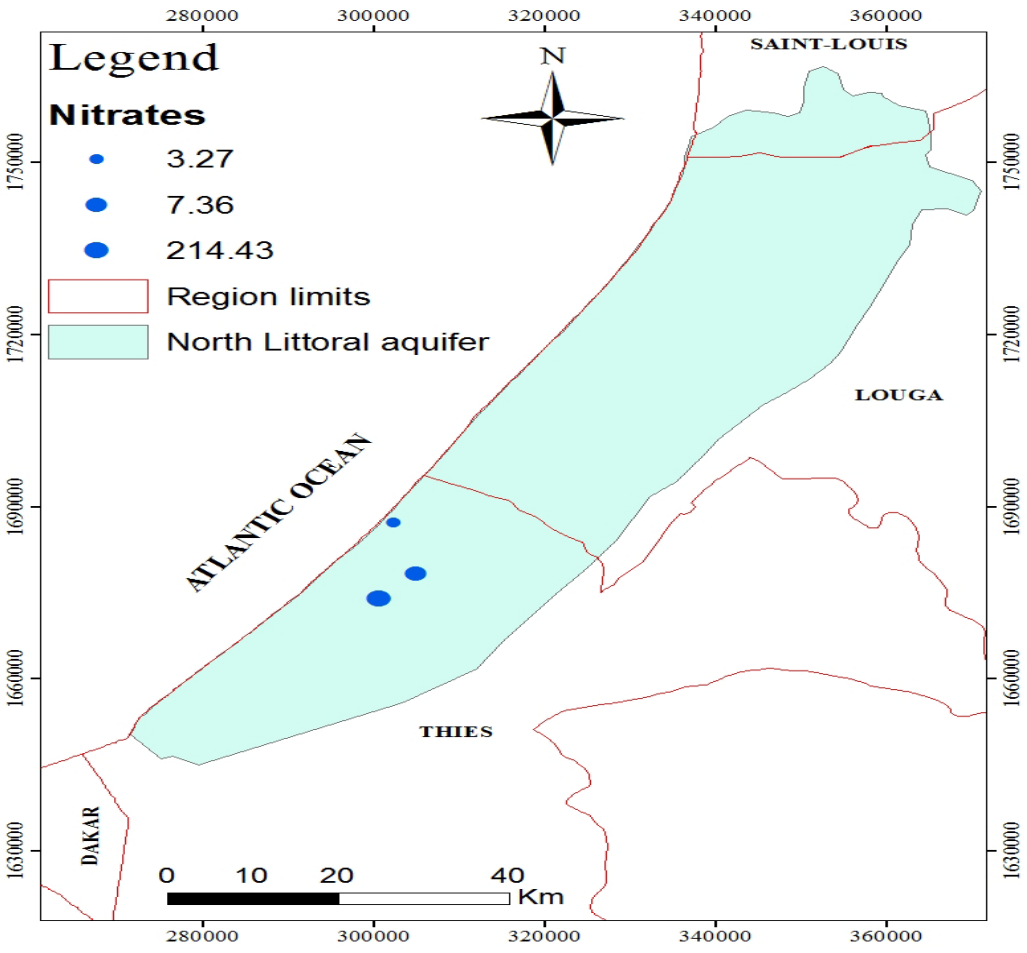

Figure 8. Distribution of nitrates in the study area

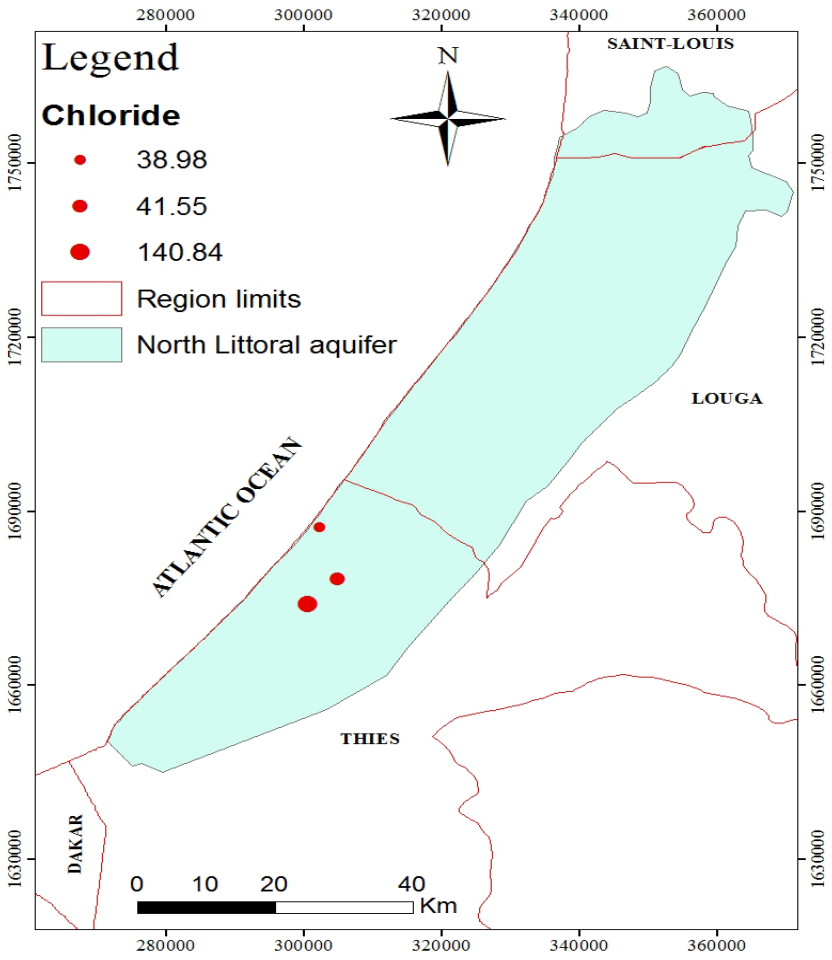

Figure 9. Distribution of chlorides in the study area

Iron ions are present at levels ranging from 0.34 to 1.68 mg/L above the limit value of 300 µg/L defined by the World Health Organization

The results of chemical analysis were plotted in the Piper diagram to determine the chemical facies of the waters. Figure 10 shows that the groundwater coastal aquifer is characterized by a sodium and potassium chloride facies linked to the proximity of the sea.

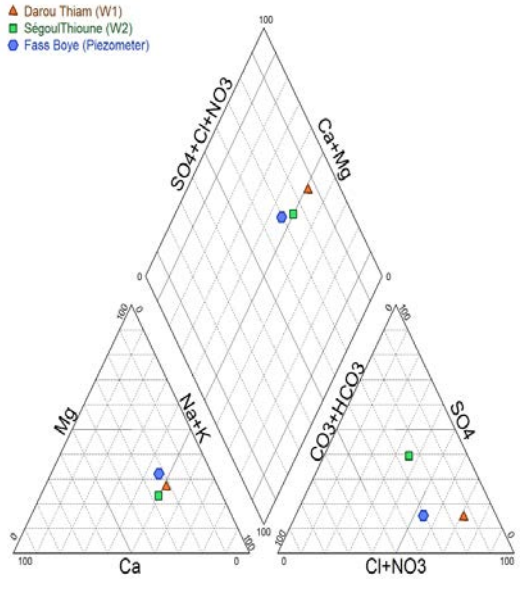

Figure 10. Piper Diagramm.

4. Conclusion

This study showed that only well water from the Darou Thiam village has chemical contamination with nitrates and, to a lesser extent, chlorides and sodium. On the other hand, water samples from Ségoul Thioune well and Fass Boyes piezometer are drinkable. This situation is linked to several factors including the vulnerability of the water table linked to the low depth of 27 m. On the other hand, poor agricultural practices using fertilizers combined with the lack of waste management (87% of households dump garbage and wastewater on the ground, 70% eliminate faeces in latrines and 20% in the free air) may be a cause. The mineralization of the water table is relatively weak to strong because of the EC are strongly influenced by the ions NO_3^-, Cl^- and Na^+. The alkalinity of the groundwater is influenced by the dissolution of $HCO3^-$

The priority is to protect the water table as much as possible against contamination which can be chemical or bacterial. Therefore, the consumption of water by the populations of Darou Thiam constitutes a danger to the health of the inhabitants of Ségoul Thioune. Emphasis should be placed on an awareness program on the need to clean up the environment. It would be necessary to circumscribe the risk points, assess the number of visitors. Secondly, it would be imperative to legislate on fertilizers and pesticides and then limit the overexploitation of this coastal groundwater.

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