*Available online www.jsaer.com*

*Journal of Scientific and Engineering Research*, 2018, 5(6):316-325

**Research Article**

**ISSN: 2394-2630**
**CODEN(USA): JSERBR**

# Assessment of the Vulnerability of the Quaternary Sand Aquifer of the North Littoral of Senegal to Sea-Water Intrusion using Galdit Method

**Mahécor DIOUF[1], Saïdou NDAO[1,2], Mamadou S. DIALLO[1], Abdoulaye DIEDHIOU[1], El Hadji B. DIAW[1]**

[1]Laboratory of Science and Technology of Water and Environment (LaSTEE), Polytechnic School of Thies BP A10 Thiès, Senegal
[2]University of Thies, UFR Sciences and Technologies, Cité Malick Sy, PB 967, Thiès, Senegal

**Abstract** This article studies the vulnerability of the Quaternary sands of the northern Senegal aquifer coastline to saline intrusion using an index mapping method, the GALDIT method. The analysis of the vulnerability map allows us to distinguish four zones of gradual vulnerability: a very high vulnerability zone located in the extreme north of the study area, which is characterized by high chloride concentrations and a very high electrical conductivity; areas of strong vulnerability located in the northern part of the study area, and the south of Kayar characterized by relatively low hydraulic gradients (1 and 3 m); areas of medium vulnerability located in the South, on the coastal fringe, and in the North characterized by average hydraulic gradients (4 and 6 m) and an area of low vulnerability located in the center of the study area with piezometric head up to 28 m that control the flow of the aquifer. The study showed that at a very high vulnerability areas, measurement points revealed very high electrical conductivities with an average value of 15,802 µS/cm, and chloride concentrations above 500 mg/l. Moreover, in the north of the study area, the impact of salt intrusion is evident. High concentrations of chloride and electrical conductivity have made this water aquifer unsuitable for irrigating vegetable crops. Nowadays, this part of the aquifer is very little exploited because of its proven sensitivity to saline intrusion. Optimizing groundwater exploitation will involve promoting water-efficient irrigation methods such as drip irrigation with an irrigation efficiency of over 95%.

**Keywords** vulnerability, sea-water, Intrusion, costal aquifer, GALDIT, Senegal

## 1. Introduction

The study area is a semi-arid region located in northwestern Senegal. It corresponds to the area of Niayes located along the sea coast, between Dakar and St. Louis, on a strip of 180 km long and 5 to 30 km wide. The quaternary sand aquifer covers an area of 2,300 km². The reservoir of the Quaternary sand sheet has two geologically distinct sets: West of the "Thiès-Saint-Louis" road, the aquifer consists of sandy and sandy-clay deposits resting on the marly or marl-limestone bedrock of the Eocene [1] and in the East, the quaternary cover diminishes and only remains in the form of a superficial dune sand that rests on the upper Lutetian limestones. This reservoir is in touch with salty waters of the Atlantic Ocean to the west. The thickness of the reservoir is mainly related to the morphology of its tertiary impervious substratum. This area of the Niayes, made up of ancient valleys and inter-dune depressions, is currently the main horticultural production area of the country, with more than 60% of the country's production and 80% of horticultural exports [2].

Nowadays, the study area is facing a serious rainfall deficit that is having a negative impact on its socio-economic development. Groundwater is the only water resource available to meet agricultural needs, household needs, livestock watering, mining industries (Chemical Industries of Senegal (ICS) and Grande Cote Operation (GCO), and the supply of drinking water to one part of the Senegalese capital (Dakar). The intensification of agricultural activities on coastal fringes observed in recent years under the program "accelerate the pace of Senegalese agriculture" (PRACAS), population growth and adverse weather conditions (persistent decline in rainfall since 1972) are factors that contribute to the decrease in the aquifer system reserves and the degradation of groundwater quality.

It has been clearly demonstrated that the level of the Quaternary sands aquifer on the northern coast of Senegal has steadily declined since the 1970s following droughts that hit the Sahel [3]. This continuous drop in the water table reached nearly five meters in some measurement points between 2000 and 2016 [3]. The current degree of mineralization of the groundwater far exceeds limits recommended by WHO for drinking water quality [3]. Salinization of coastal aquifers is a function of the hydrogeological, climatic, demographic and social context. It results from the anthropogenic and climatic impact on the dynamics of the aquifer. It is strongly influenced by the difference in loads between the sea level and the piezometric load of the water table. It is exacerbated by the exploitation of the aquifer and climate change. It is in that perspective that this research work proposes, on the one hand, to analyze the hydrogeochemical data collected during thirty piezometric monitoring campaigns by DGPRE, and on the other hand, to map the vulnerability of the water table to saline intrusion by the GALDIT method.

The objective of this research is to map the degree of sensitivity of the Quaternary sand table of the northern coast of Senegal to the saline intrusion through an index mapping method, the GALDIT method. This study will contribute to the identification of strategic orientations allowing a full productive potential of the Niayes ecosystem, while taking into account the dimension of the long-term preservation of the water resource, and the anthropic and climatic constraints.

## 2. Materials and method

### 2.1. Presentation of the study area

The North littoral of Senegal (denominated Niayes) area registers administratively in the four regions bordering the maritime fringe of northern Senegal including Dakar, Thiès, Louga and Saint-Louis (Figure 1) .It extends over a length of about 180 km and on a 20 to 30 km wide depending on the studies [4], [5]. Figure 1 shows the area with the main municipalities concerned.

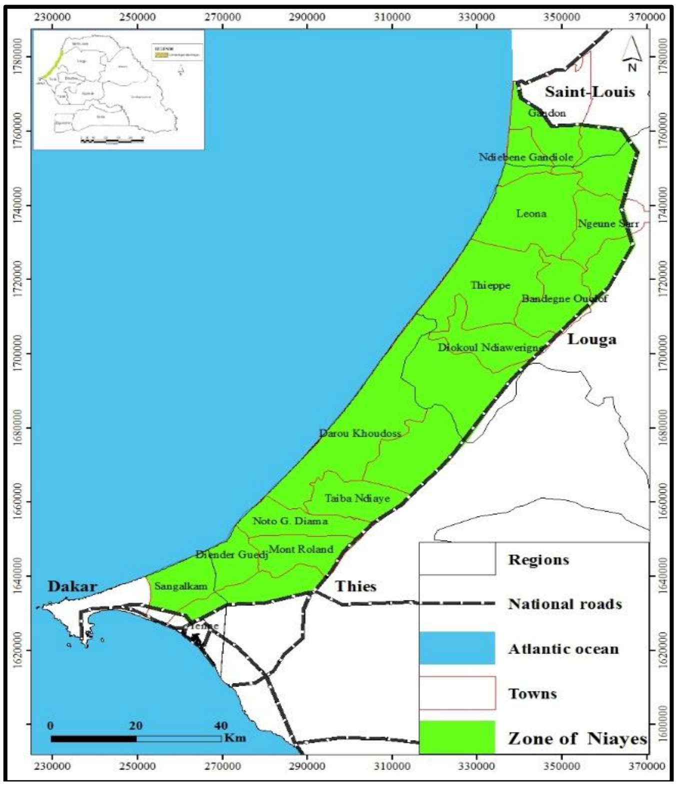


*Figure 1: Map of the Niayes area*

With decentralization, several municipalities have been built on this coastal strip. They are Sangalcam, Diender, Bayakh, Kayar, Notto Gouye Diama, Mboro, Darou Khoudos, Gandon, Léona and Thieppe, all of them are agricultural.

The study area is closed inter-dune depressions with a flush or uplifted aquifer and are characterized by a succession of dunes and depressions. This zone includes several ecological units and contains very important biological and mining resources whose exploitation deserves special attention.

### 2.2. Method and Data

The GALDIT method is an example of cartography dedicated to coastal aquifers and incorporates the notion of going back up from the sea level. The determination of the groundwater vulnerability index, in relation to a saline intrusion, is based on the combination of six parameters that are: Groundwater occurrence, Aquifer hydraulic conductivity, Depth to groundwater Level above sea level, Distance from shore, Impact of existing status of seawater intrusion and the Thickness of aquifer. The initials of these six parameters form the acronym "GALDIT". The GALDIT method was developed by Chachadi and al. [6]. It estimates the vulnerability of a coastal water table to saline intrusion. GALDIT factors represent measurable parameters for which data are generally available. The basic assumption is that the substratum of the aquifer is below mean sea level. The principle of the GALDIT method provides three significant parts: weight, rank and class. Each GALDIT factor is evaluated respecting the other; this in order to determine the relative role of each factor. The following table presents the specific method for characterizing the vulnerability of a coastal aquifer:

**Table 1:** Specific method for characterizing the vulnerability of a coastal aquifer

| Parameter | Weight (W) | Rank (R) | | | |
|---|---|---|---|---|---|
| | | **Very low** | **Low** | **Medium** | **High** |
| G | 1 | 2.5 | 5 | 7.5 | 10 |
| | | Waterproof or recharge at the coast | Semi-captive | Free | Captive |
| A | 3 | <5 | 5-10 | 10-40 | >40 |
| L | 4 | >2 | 1.5-2 | 1-1.5 | <1 |
| D | 4 | >100 | 750-1000 | 500-750 | <500 |
| I | 1 | <100 | 100-250 | 250-1000 | >1000 |
| T | 2 | <5 | 5-7.5 | 7.5-10 | >10 |

A grade is assigned to the four classes of each parameter. This score is between 2.5 and 10. The resulting values of the GALDIT index are obtained by aggregation of values of the parameters weighted significantly by the formula:

$$\boldsymbol{IG} = \sum_1^6 (\boldsymbol{R_i} * \boldsymbol{W_i}) \Big/ \sum_1^6 \boldsymbol{W_i} \quad \textbf{(1)}$$

With R and W the ranks and weights of different parameters respectively and IG, the GALDIT index.

As part of this study, the classification below is proposed according to values of the GALDIT index and color codes are attributed:

**Table 2:** GALDIT vulnerability index

| Vulnerability class | IG | Color code |
|---|---|---|
| Very high vulnerability: | >7.5 | |
| Strong vulnerability: | 6 à 7.5 | |
| Average vulnerability: | 5 à 6 | |
| Low vulnerability: | < 5 | |

These four classes will be represented on the map by a color code. The cartographic treatment allows to present values distribution of the electrical conductivity and chloride concentrations making it possible to confirm the degree of sensitivity of the sheet with respect to the saline intrusion.

Data used in this study come from databases of the "Directorate of Management and Planning of Water Resources (DGPRE)", the National Agency of Civil Aviation and Meteorology (ANACIM) and various studies on the Niayes area. The electrical conductivity and chloride concentration data extracted from the DGPRE database are superimposed on the vulnerability map established by the GALDIT method.

## 3. Results and discussions

### 3.1. Piezometric situation of the aquifer

The piezometric map below shows two piezometric domes, one in the Taiba Ndiaye zone, and another in Thiambam and a low zone with very low hydraulic loads.

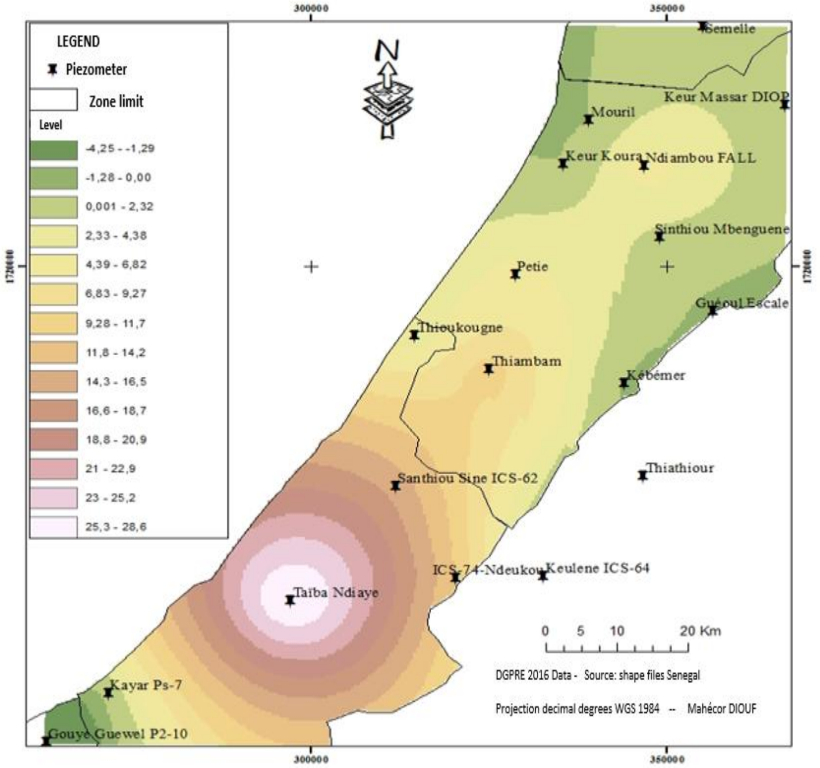


*Figure 2: Piezometric map of the aquifer in 2016*

The flow of the aquifer is dominated by the piezometric dome of Taiba located at +28.6 m. The flows follow a hydraulic gradient on both sides of this dome [7], [8], [9]. At the center of the study area is a second piezometry dome of average amplitude of + 6m that controls the flows to the northeast and northwest of the study area. The latter is fed in part by the dome of Taiba Ndiaye. Figure 2 shows that low areas are located at the extreme north of the study area at Mourel and southwest of Kayar at Gouye Guewel.

The current dynamics of the tablecloth slows down the progression of the salt wedge. In fact, hydraulic loads tend to push the abrupt interface towards the sea. South of the study area (Kayar height) to the center west (Keur Koura height) through Ndiambou FALL, the forts hydraulic gradients (> + 4m) push back the freshwater / salt water interface towards the sea. In the Northern zone (Mourel-Semel), a very weak hydraulic gradient, sometimes lower than the level of the sea, is observed. This can induce a high vulnerability of the water table vis-à-vis the saline intrusion. Thus, due to the pressure balance between freshwater and seawater, the steep area tends to move towards the mainland. This area would certainly be the most affected by salt intrusion.

### 3.2. Current hydrogeochemical situation of the aquifer

*3.2.1. Distribution of electrical conductivity values*

Figure 02 below shows measurement point's positions with a long chronicle allowing a sensitivity analysis of the aquifer at the saline intrusion. As part of this study, we proposed three classes of electrical conductivity: <600 µS/cm, [600-800 µS/cm,] and > 800 µS/cm.

Previous studies have shown that electrical conductivity values below 600 µS/cm correspond to groundwater that is not influenced by marine intrusion. On the other hand, electrical conductivity values> 800 µS/cm correspond in principle to groundwater influenced by saline intrusions and other anthropogenic contaminations.
Figure 3 below shows three classes of electrical conductivity: a zone with low conductivity (not influenced by marine intrusions), an intermediate zone and a high electrical conductivity zone (a priori strongly influenced by marine intrusions).

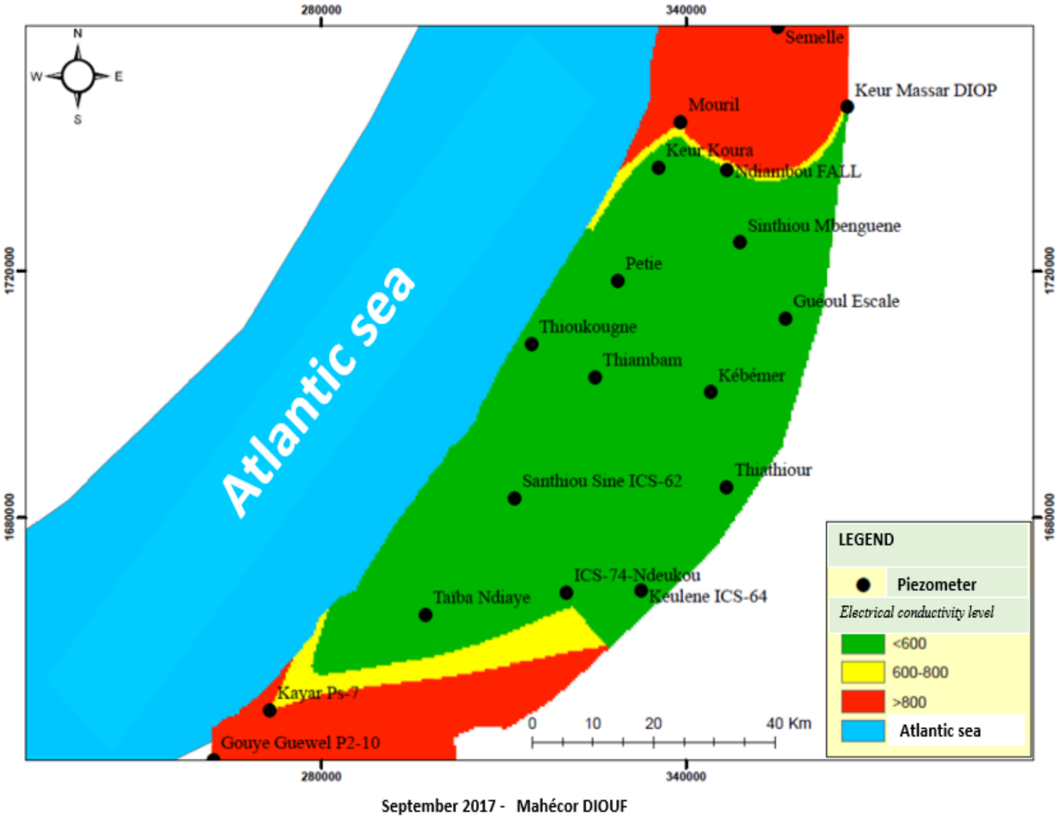


*Figure 3: Electrical conductivity distribution board*

The study area shows very low electrical conductivities in the central area north of Kayar to the south of Mourel. This area corresponds to the influence zone of piezometric domes of Taiba Ndiaye and Thiambam. In this zone, hydraulic gradients are positive with loads ranging from +28 to +6 m. This explains the lack of water of marine origin. These piezometric domes also represent areas of possible recharge of the water table, which certainly allows the water softening in this area.
On the other hand, we observed a very typical situation at the extreme north and south of the study area. In fact, electrical conductivities are 15.820 µS/cm at Sole and 10.251 µS/cm at Gouye Guewel. These very high values of electrical conductivities indicate the presence of marine origin water. As a reminder, the electrical conductivity of seawater is about 30,000 µS/cm for 20 g/l. Electrical conductivity values observed at the points of measurement of Semelle and Gouye Guewel are very similar to the electrical conductivity values of seawater. This probably reflects a strong influence of the sea in this zone. Between the zones of marine influence and the center of the Quaternary sand aquifer of Senegal's northern coast, which controls the recharge of the aquifer, is an intermediate zone characterized by electrical conductivity values of 600 and 800 µS/cm. These values show a weak influence of marine origin water. This buffer zone is located in the North between Mourel and Semelle, and in the South between Kayar and Taïba Ndiaye. From a hydrodynamic point of view, this area is characterized by relatively low hydraulic loads nearing even sea level in some places.

*3.2.2. Distribution of chloride concentration values*

Figure 4 below shows the distribution of chlorides in the study area. We have proposed in this study three classes of chloride concentration: $<3.10^{-1}$ g/l; $[3.10^{-1} - 5.10^{-1}$ g /l] and $> 5.10^{-1}$ g/l.

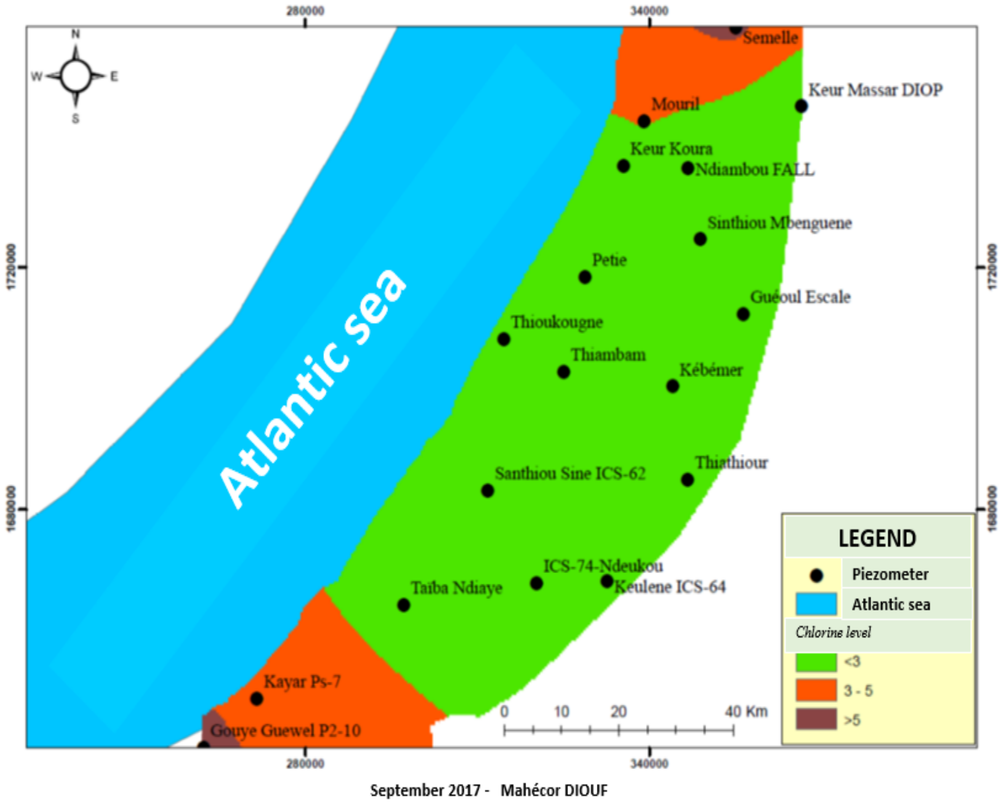


*Figure 4: Chlorine distribution map*

The central zone is characterized by chloride concentrations below $3.10^{-1}$ g/l. This area is located in the south of Taiba Ndiaye and in the north of Keur Koura. Chloride concentrations range from 96 mg/l in the center to 250 mg/l in the south. This low concentration is indicative of an insensitive area to marine intrusion. The extreme North and South are characterized by very high chloride concentrations that are higher than $5.10^{-1}$ g/l. This strong presence of chlorides is indicative of the presence of marine origin water in these areas. Between the highly chlorinated zones and the central zone is an intermediate zone characterized by chloride concentrations between $3.10^{-1}$ and $5.10^{-1}$ g/l. These areas are located in the Niayes of Kayar in the South and the area of Mourel in the North. These values of the chloride concentration indicate a weak influence of marine origin water in the aquifer. The disadvantage of the high chloride content is the unpleasant taste they impart to water from concentrations above 250 mg/l, especially when it comes to sodium chlorides.

*3.2.3. Chemical facies observed below*

The Figure 5 presents the chemical facies of the water samples taken during the last monitoring campaign (December 2017) carried out by the DGPRE as part of the implementation of the Niayes's economic development program. The Piper diagram is composed by two triangles that represent the cationic and anionic facies, and by a rhombus synthesizing the global facies. The predominance or not of the ions is defined according to the position of the analyzed sample on the diamond, which is composed of four faces and four vertices. The coming Piper diagram of the water samples collected in eighteen piezometers distributed in the study area is as follows:

This diagram in figure 5 shows the facies of the different types of water encountered in the Quaternary sand table of the northern coast of Senegal. The facies of the waters, sampled during the last monitoring campaign of the DGPRE (December 2017), compared to the results of the previous campaign (May 2017 - before the rainy season) illustrate a great inertia of the behavior of the studied aquifer between its high and low level. Chemical facies observed in the different measurement points are:

1- A calcium and magnesium chloride facies located at the extreme north and south of the study area. This part of the aquifer is very mineralized. This facies is representative of a water highly marked by solutions of marine origin with high concentrations of chlorides, potassium and nitrates. The magnesium chloride facies is the most representative of the water table located mainly in the north of the study area, in the Saint-Louis region. This type of water is a mixture of groundwater and seawater. Thus, chlorides are of marine origin.

2- A magnesium and calcium bicarbonate facies that is located in the center of the study area between Mboro and Keur Koura. This facies is typically representative of karst aquifer. This confirms lateral contributions coming from the aquifer of Lutetian limestones up to Kébémer. In this zone, there is a lithological discontinuity between the two layers.

3- A sodium chlorite facies, which is located in the south of the Mboro.This area is characterized by medium mineralization. This facies is characteristic of waters weakly influenced by saline intrusion.

These different facies underline the complexity of the hydrogeochemical processes that control the salinity of the Quaternary sand waters of the northern coast of Senegal. The predominance of chloridic facies shows the influence of the sea on the aquifer mineralization.

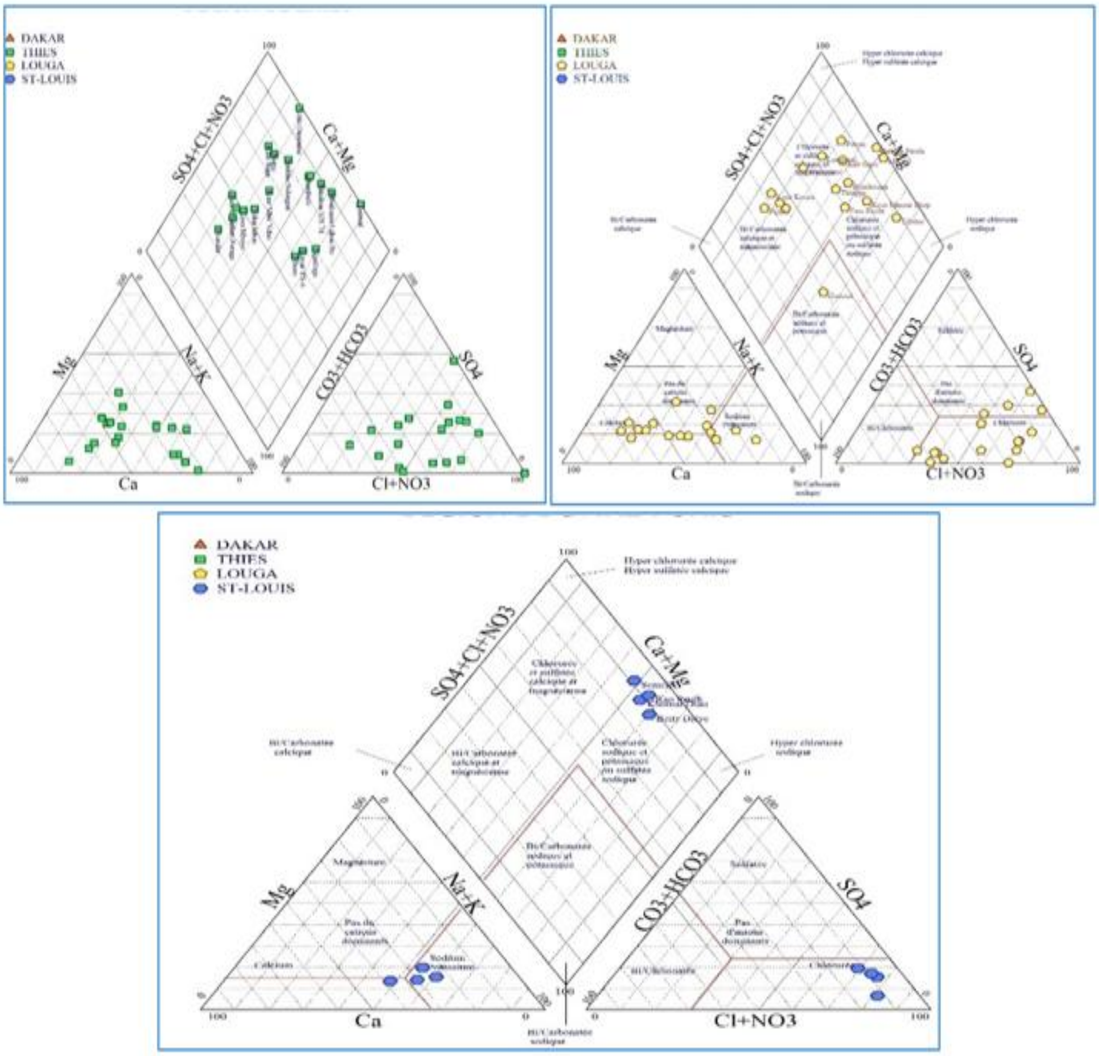


*Figure 5: Observed chemical facies of the aquifer*

### 3.3. Vulnerability mapping of the aquifer to saline intrusion

The GALDIT index mapping of the aquifer quaternary sands of the northern coast of Senegal highlights zones of gradual vulnerability. We have proposed in this study four classes of vulnerability for the saline intrusion [10]. The calculated input data obtained using the GALDIT method gave results presented in the following table:

**Table 3:** Input Data

| No. | Measuring points | Geographical coordinates | | GALDIT parameter | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | G | | A | | L | | D | | I | | T | | IG |
| | | X Cord | Y Cord | R | P | R | P | R | P | R | P | R | P | R | P | |
| 1 | Semelle | -16.3536 | 15.9125 | 7.5 | 1 | 10.0 | 3 | 2.5 | 4 | 10 | 4 | 5 | 1 | 10 | 2 | 7.7 |
| 2 | Keur Koura | -16.5350 | 15.7044 | 7.5 | 1 | 2.5 | 3 | 2.5 | 4 | 5 | 4 | 5 | 1 | 2.5 | 2 | 3.7 |
| 3 | Mouril | -16.5019 | 15.7708 | 7.5 | 1 | 10.0 | 3 | 2.5 | 4 | 7.5 | 4 | 5 | 1 | 10 | 2 | 6.8 |
| 4 | Ndiambou FALL | -16.4297 | 15.7014 | 5 | 1 | 7.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 4.8 |
| 5 | Keur Massar DIOP | -16.2453 | 15.7947 | 7.5 | 1 | 5.0 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 4.5 |
| 6 | Thioukougne | -16.7278 | 15.4444 | 7.5 | 1 | 7.5 | 3 | 2.5 | 4 | 5 | 4 | 5 | 1 | 10 | 2 | 5.7 |
| 7 | Kébémer | -16.4525 | 15.3750 | 5 | 1 | 2.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 3.8 |
| 8 | Thiambam | -16.6300 | 15.3953 | 7.5 | 1 | 2.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 4.0 |
| 9 | Guéoul Escale | -16.3381 | 15.4842 | 5 | 1 | 2.5 | 3 | 2.5 | 4 | 2.5 | 4 | 3 | 1 | 10 | 2 | 3.7 |
| 10 | Sinthiou Mbenguene | -16.4086 | 15.5956 | 7.5 | 1 | 2.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 4.0 |
| 11 | Petie | -16.5964 | 15.5378 | 7.5 | 1 | 10.0 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 5.5 |
| 12 | Taïba Ndiaye | -16.8872 | 15.0447 | 5 | 1 | 5.0 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 7.5 | 2 | 4.0 |
| 13 | Santhiou Sine ICS-62 | -16.7517 | 15.2172 | 7.5 | 1 | 5.0 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 7.5 | 2 | 4.2 |
| 14 | Thiathiour | -16.4272 | 15.2361 | 7.5 | 1 | 2.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 10 | 2 | 4.0 |
| 15 | Keulene ICS-64 | -16.5572 | 15.0833 | 7.5 | 1 | 7.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 7.5 | 2 | 4.7 |
| 16 | ICS-74-Ndeukou | -16.6717 | 15.0797 | 5 | 1 | 7.5 | 3 | 2.5 | 4 | 2.5 | 4 | 5 | 1 | 7.5 | 2 | 4.5 |
| 17 | Gouye Guewel P2-10 | -17.9278 | 16.4048 | 7.5 | 1 | 5.0 | 3 | 7.5 | 4 | 7.5 | 4 | 5 | 1 | 10 | 2 | 7.2 |
| 18 | Kayar Ps-7 | -17.5593 | 16.4858 | 7.5 | 1 | 10.0 | 3 | 2.5 | 4 | 5 | 4 | 5 | 1 | 7.5 | 2 | 5.8 |

The L and D weights for hydraulic loading and distance from the coast are the most important values in our study since the aquifer permeability values and the aquifer type are relatively homogeneous.

Graphical processing, using ArcGIS software, allows us to present in Figure 6 below the different vulnerability classes:

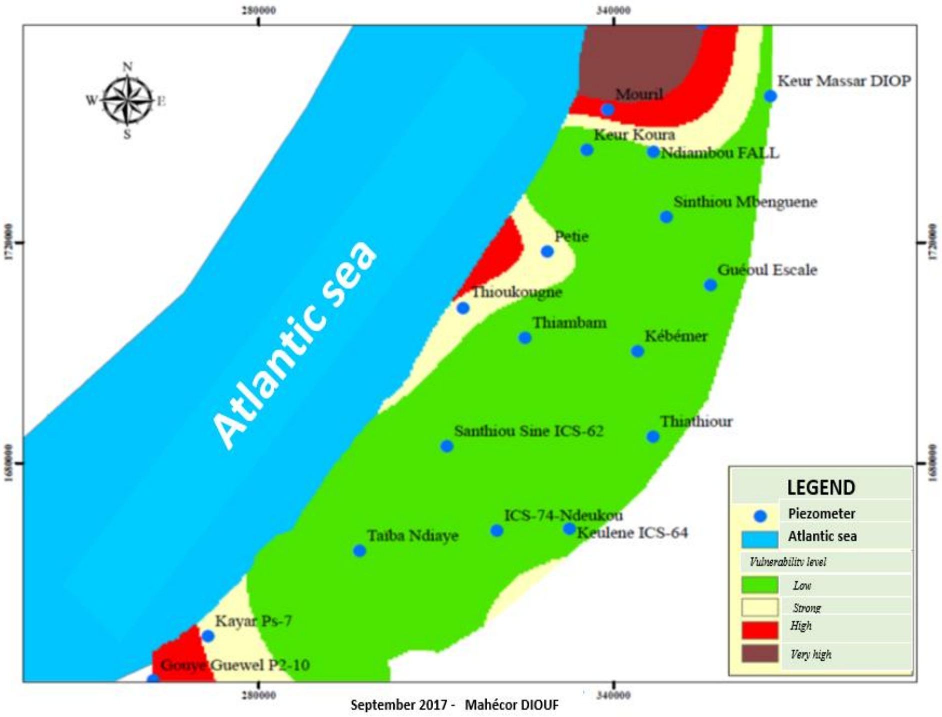


*Figure 6: Map of vulnerability of the aquifer to saline intrusion*

The analysis of figure 6 reveals four classes of vulnerability:

- A zone of very high vulnerability, which is located at the extreme north of the study area around the Semelle piezometer (Gandiol) in the Saint-Louis region. This part of the aquifer is characterized by hydraulic load values below sea zero. This area is currently influenced by the sea since 2003, date of marine invasion following the construction of the watershed. Dounde Baba DIEYE who led the displacement of the mouth up to the village of Taré located five kilometers from Mourel.

- Areas of high vulnerability located in the north of the study area at Mourel, on the coastal fringe west of Thioukougne and south of Kayar in the Gouye Guéwel area. These areas are characterized by relatively low hydraulic gradients with values between 1 and 3 m. The high exploitation of the aquifer in these areas for agricultural needs leads to changes in the aquifer dynamics in some places. It is noted that a one-meter drop following a pumping causes a marine water level increase from height to forty meters.
- Areas of medium vulnerability are located in the South around Kayar, on the coastal fringe around Thioukougne, and in the North at Keur Koura. These three zones are characterized by hydraulic gradients that vary between 4 and 6 m.
- A weak vulnerability zone located in the center of the study area. This area houses the piezometric dome of Taiba Ndiaye. The piezometric loads reach +28 m and dissipate on both sides of the Taiba area. These freshwater loads tend to repel the salty bevel. To further refine our analysis, we propose to superimpose the vulnerability map to maps of chloride concentrations and electrical conductivities.

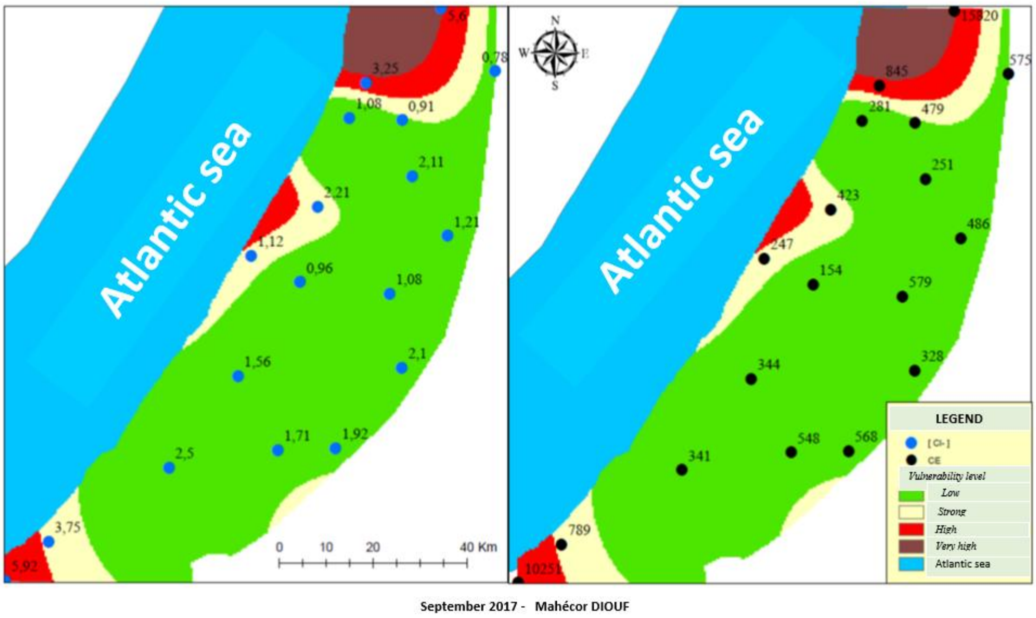


*Figure 7: Superposition of the vulnerability map to chlorine and electrical conductivity maps*

This map shows that at very high vulnerability areas, measurement points revealed very high electrical conductivities, with an average value of 15,802 µS/cm, and chloride concentrations above 500 mg/l. In the Gandiol area, the impact of saline intrusion is now known in most of the capture points used by market gardeners. High concentrations of chlorides and electrical conductivity have made groundwater unsuitable for irrigating vegetable crops. Today, this part of the aquifer is very little exploited because of its proven sensitivity to saline intrusion. In areas of high and medium vulnerability, chloride concentrations are between 300 and 500 mg/l and electrical conductivities between 600 and 800 µS/cm. The optimization of the exploitation of the aquifer in areas of high and medium vulnerability is essential in a perspective of sustainable management of the water resource. This optimization will involve promoting water-efficient irrigation methods such as drip irrigation at the expense of traditional (manual) irrigation systems that cause a lot of water loss.

The center of the study area has a low sensitivity to saline intrusion. This area, which houses the two piezometric domes that control the flow of the aquifer system, extends north from Kayar to Mourel and slips into the interior of the continent. Measurement points in this zone showed low electrical conductivities, less than 600 µS/cm and chloride concentrations less than 300 mg/l. The quality of these waters is good and shows no trace of saline intrusion. This area, characterized by hydraulic loads between 4 and 28 m, must be well monitored to avoid a significant drawdown. A drop in the piezometric level will lead to a modification of the hydrodynamic relationship between freshwater and seawater. We also note that this zone has a strong influence on areas of medium and high vulnerability. Heavy punctures on this part of the water table correlated with the drop in rainfall and the rise in sea level observed in recent years will expose the water table to saline intrusion.

**Conclusion**

Hydrogeochemical analysis of chronic data over the last thirty years on the electrical conductivity and the concentrations of salinity indicator ions taken on the eighteen points of measurement showed a progression of the aquifer salinization in the extreme North and South of the region studied. Nowadays, this progression tends to reach the center of the study area. This situation is confirmed by the mapping the vulnerability of the aquifer to saline intrusion, which revealed four classes of gradual vulnerability. The salinity increase can be explained by the rainfall decrease associated with the occurrence of groundwater withdrawals and the rise in sea level observed in recent years with the development of irrigation, which is needed as a palliative decrease in rainfall in the region. The predominance of chlorinated facies and the high values of electrical conductivities confirm the vulnerability of the aquifer to saline intrusion.

The saline intrusion represents a major pollution risk for the quaternary sand aquifer of Senegal's northern coast, which is a strategic reservoir for the country. This risk is actually accentuated because of the increase in the frequency and intensity of drought periods, but also in response to the significant population increase in the coastal zone. It will become even more important during the rise of the sea level related to climate change. The good management of this aquifer, therefore, requires better knowledge and better detection of saline intrusions. The hydrodynamic functioning of the quaternary sand aquifer of the northern coast of Senegal is favorable to the protection of the aquifer from saline intrusion. However, it is important to monitor the evolution of piezometric domes that control groundwater flows by modeling the effect of climate change on the dynamics of this aquifer.

**References**

[1]. NOËL, Y., (1978). Etude hydrogéologie des calcaires lutétiens entre Bambey et Louga (2ème phase). Rapport BRGM 78 Dak 02, 82p.

[2]. Direction de l'Horticulture (DHort), (2016). Rapport d'activité annuel. Dakar, Ministère de l'agriculture, 256p.

[3]. Mahécor DIOUF et al, (2017). Impact anthropique et climatique sur la dynamique de la nappe des sables quaternaires du littoral nord du Sénégal. Revue Cames – Sci. Appl. & de l'Ing., Vol. 2(1), pp. 37-41. ISSN 2312-8712

[4]. MALOU Raymond, (2004). Impact of climate on groundwater resources in the Sudano-Sahelian zone. PhD thesis in Natural Sciences of Applied Geology. UCAD, 143p

[5]. DIAW E. B., Mamadou L. Lo, Mamadou Wade, Seydou Ndao, Ablaye Diallo, and Grégoire SISSOKO, (2016). Numerical modeling of solute transport: prediction of the risks of contamination of the Niayes aquifer (Senegal) by pesticides; International Journal of Innovation and Applied Studies, Vol. 17 No.4: 1358-1372.

[6]. Chachadi A.G. & Lobo-Ferreira, J.P., (2001). Sea water intrusion vulnerability mapping of aquifers isung GALDIT method. Proc. Workshop on modeling in hydrogeology, Anna University, 143p.

[7]. Aller, L., Bennett, T., Lehr, J.H. & Petty, R. J., DRASTIC, (1987). A standardized system for evaluating groundwater pollution potential using hydrogeologic settings, U.S. EPA Report 85p.

[8]. B.R.G.M., (1987). Etude des ressources en eau souterraine du Sénégal. Rapport campagne de prospection géophysique, 70p + annexes.

[9]. Direction de la gestion et de la planification des ressources en eau (DGPRE), (2016). Suivi piézométrique des nappes du littoral nord. Rapport d'activité, 356p.

[10]. Lobo-Ferreira, J.P, Chachadi, A.G., Diamantino, C., & Henriques, M.J. (2005). Assessing aquifer vulnerability to sea-water intrusion using GALDIT method: Part 1 – Application to the Portuguese Aquifer of Monte Gordo. IAHS and LNEC, Proceedings of the 4th The Fourth Inter Celtic Colloquium on Hydrology and Management of Water Resources, held at Universidade do Minho, Guimarães, Portugal, July 11- 13, 2005.